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MINERALOGY.

BY

J. H. COLLINS, F.G.S.,

Author of "A Handbook to the Mineralogy of Cornwall and Devon,"
"A First Book of Mineralogy," etc.
Honorary Secretary to the Mineralogical Society of Great Britain and Ireland, etc.

VOL. I.—THE GENERAL PRINCIPLES OF MINERALOGY.

With 579 Illustrations.

NEW YORK:
G. P. PUTNAM'S SONS,
182 FIFTH AVENUE.

J. M.
Edward Bright

PREFACE.

In preparing this work for the press, I have endeavoured primarily to keep in view the needs of the same class of students as my *First Book of Mineralogy* was written for, viz., practical working miners, quarrymen, field geologists, and students of the Science Classes in connection with the Department of Science and Art. I believe the work properly studied will enable its students to pass the Government Examinations with credit; but I hope it will do much more than this, and that my readers will become practical mineralogists, able to determine the nature of such unknown species of minerals as may fall in their way, and to appreciate the relations borne by the science of Mineralogy to the sister sciences of Chemistry, Geology, Metallurgy, and Mining. I have endeavoured throughout to use plain language, and in dealing with Crystallography, I have remembered that a majority of my readers were not likely to have had much mathematical training. Consequently it has been necessary in some instances to adopt somewhat roundabout methods of definition or descriptions. The liberality of the Publishers in allowing me such a very large number of woodcuts, has much assisted me in this direction.

Believing as I do that the Crystallographic system of Professor Miller is the best yet invented, I have to some extent led up to it through the apparently simpler but less perfect system of Naumann, which is adopted by many science teachers, and which I myself used in the *First Book* already mentioned. In works of this character there can of course be very little that is absolutely new, but I have endeavoured to condense or to simplify much of what has already been written. Among works particularly made use of, I may mention those of Nicol, Brooke and Miller, Mitchell (in Orr's *Circle of the Sciences*), and Dana.

My thanks are due to Mr. B. Kitto, F.G.S., of Camborne, for his valuable assistance in correcting many of the proof sheets.

This volume will be followed by another (now in the press), giving detailed descriptions of most of the minerals known to science.

In conclusion, I would strongly urge teachers of Mineralogy not to attempt to teach either from this book or any other without constant reference to models, and especially to actual specimens of the minerals referred to.

J. H. C.

57 Lemon Street, Truro,
October 1877.

CONTENTS

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

CHAPTER VI.

CHAPTER VII.

CHAPTER VIII.

CHAPTER IX.

CHAPTER X.

CHAPTER XI

CHAPTER XII.

CHAPTER XIII.

CHAPTER XIV.

CHAPTER XV.

CHAPTER XVI.

CHAPTER XVII.

CHAPTER XVIII.

CHAPTER XIX.

CHAPTER XX.

CHAPTER XXI.

CHAPTER XXII.

CHAPTER XXIII.

CHAPTER XXIV.

CHAPTER XXV

CHAPTER XXVI.

CHAPTER XXVII.

MINERALOGY.

THE GENERAL PRINCIPLES OF MINERALOGY.

CHAPTER I.

INTRODUCTION.

1. "**Minerals** are *natural, homogeneous, inorganic* bodies." This definition includes many substances not usually regarded as minerals, such as *water* in its several forms of solid, liquid, and gas; air; the gases given off from volcanoes or from fissures in earthquake regions; and liquids like sulphuric acid and naphtha which are naturally produced in certain districts.

A strict application of the definition would exclude all substances of vegetable origin, such as peat, coal, and amber, but it has been found convenient to include descriptions of these and a few other similar substances in mineralogical treatises, and we have not departed from this practice in the present volume.

2. **Rocks** are usually *mineral substances* but not *minerals.* Some, like *granite, gneiss,* and *elvanite,* are aggregates of several distinct minerals; others, like *dolomite, serpentine,* and *gypsum,* are simply impure massive forms of the minerals of the same names. The following list of the minerals which most frequently enter into the composition of rock-masses or of veinstone, occupying fissures in such masses—*rock-formers* as they may be termed—will be useful to the student.

A.—MINERALS COMMON IN ROCK MASSES.

Quartz.
The Felspars.
Kaolin.
The Micas.
Tourmaline (*Schorl*).
Chlorite.
Garnet.
Amphibole (*Hornblende*).
Pyroxene (*Augite*).
Serpentine.
Olivine.
Gypsum.
Apatite.
Calcite.
Dolomite.
Halite (*Rock Salt*).
Sulphur.
Graphite.
Magnetite.
Hematite.
Limonite.
Chalybite.
Pyrites.
Coal.

B.—MINERALS COMMON AS VEINSTONES.

Quartz.
Calcite.
Barytes.
Fluor.
Galena.
Chalcopyrite.
Mispickel.
Pyrites.
Limonite.
Hematite.
Chalybite.
Chlorite.

The study of rocks belongs to **Geology**, of which science Mineralogy may be regarded as an important branch.

3. Minerals have many peculiar *mechanical*, *optical*, and other *physical* characters. Thus, some like quartz and the diamond are very hard, others like talc and graphite are very soft. Most minerals at ordinary temperatures are solid, but some few, like mercury, naphtha, and water, are liquid, and others like carbonic acid are gaseous. The complete study of these properties belongs to **Physics**, but a considerable portion of the present volume will be devoted to the consideration of these properties.

4. Minerals have many *chemical* properties; thus, some like witherite are poisonous, others like rock-salt form valuable additions to food, or like mercury are of great value in medicine. Some are fusible, others infusible; some are soluble in water or acids, others quite insoluble. The complete study of these properties belongs to the science of **Chemistry**, and Mineralogy may be regarded as the connecting link between Chemistry and Geology.

5. General Mineralogy may be divided, for greater convenience of study, into sections as follows :—

1. FORM.
2. PHYSICAL CHARACTERS.
3. CHEMICAL CHARACTERS.
4. DISCRIMINATON OF MINERALS.
5. CLASSIFICATION.
6. DISTRIBUTION.
7. PARAGENESIS.

CHAPTER II.

OF THE FORMS OF MINERALS—IMITATIVE FORMS, ETC.

6. The researches of Graham and others have shown that inorganic matter may exist in two perfectly distinct conditions, known respectively as *crystalloid** and *colloid.*† The same portion of matter may be at one time crystalloid and another colloid, the difference being one of condition not of composition. Thus rock-crystal consists of crystalloid silica, but if a fragment be powdered, fused with carbonate of soda, dissolved in water, and precipitated by hydrochloric acid, the precipitated silica will now be in the colloid state. When in solution, crystalloids differ from colloids in some very important particulars, and on passing into the solid form the differences are still more evident.

7. **Colloid** minerals are few in number. They are totally devoid of cleavage or distinct internal structure, but they usually break with a very perfect conchoidal fracture. They occasionally, but not often, occur in what are called *imitative* forms, but are usually *amorphous* or without definite external forms.‡ As examples of true colloid minerals, we may mention opal and obsidian.

8. **Crystalloid** minerals are very numerous, they include, indeed, the great majority of mineral species. They may be either *crystallised, crystalline, or crypto-crystalline.*

a. **Crystallised** minerals are those which occur in definite geometrical forms, the properties and peculiarities of which will be dealt with in much detail in future chapters. Ordinary *rock-crystal* is a perfect example of a crystallised mineral.

---

* Ice-like, from κρύσταλλος (*crystallos*), ice; εἶδος (*eidos*), resemblance.

† Glue-like, from κολλη (*colle*), glue; and εἶδος.

‡ Formless, from α, without; and μορφη (*morphe*), form.

b. **Crystalline** minerals are such as have the peculiar internal structure observed in those which are crystallised. They consist, indeed, of a multitude of crystals confusedly crowded together, so that the external geometrical form is lost or disguised. The cavities or "vughs" of such aggregates, however, often display distinct crystals. The kind of quartz known as *cross-course spar* affords a good example of a crystallised mineral.

c. **Crypto-crystalline** * minerals are those in which the crystalline structure is so minute that it is not ordinarily observable, but it may be detected in suitably prepared specimens when examined under the microscope.† Chalcedony and agate are good examples of crypto-crystalline minerals.

9. Many crystalline and crypto-crystalline, and some amorphous minerals, occur in what are known as *imitative* forms. The chief of these are the following :—

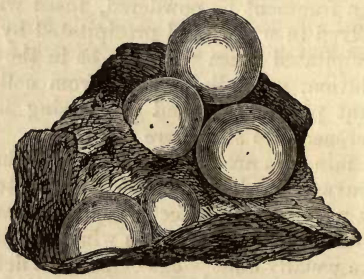

Fig. 1.—GLOBULAR.

a. **Globular,** fig. 1.—This form is often seen in *wavellite, prehnite,* and other minerals. The author has specimens of pyrites from the chalk of Dover, and of pyritous blende from Cornwall, which are detached spheres. On breaking a globular mineral, it is almost always seen to be composed of a multitude of indistinct crystals radiating from the centre, and sometimes the outside of the sphere is roughened by the projecting points of these crystals. Occasionally the true

---

* *κρυπτός* (*cryptos*), concealed.

† Transparent minerals may be cut into thin slices and examined by transmitted light; opaque minerals should be acted upon slowly by solvents, and examined by reflected light.

crystal form of these terminations may be observed, but usually they are indistinct.

b. **Reniform** (*kidney-shaped*), fig. 2.—This form is not unfrequently met with in nodules of *iron pyrites*, or other minerals which occur imbedded in clay or mud. Some kinds of red and brown hematite are called *kidney iron* from their occurrence in this form.

Fig. 2.—Reniform.

c. **Botryoidal** (*grape-like*), fig. 3.—This form is often seen in that kind of *chalcopyrites* known as *blistered copper ore.*

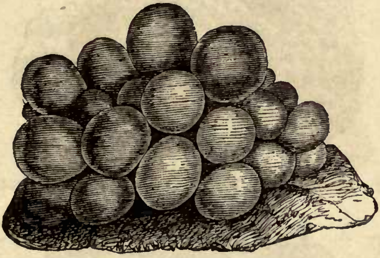

Fig. 3.—Botryoidal.

d. **Mammillary**, fig. 4.—This form is often seen in *malachite* and *blistered copper ore.*

e. **Coralloidal** (*coral-like*), fig. 5.—This structure is observable in chalcedony and aragonite, especially in specimens from Styria. It sometimes occurs in connection with earthy deposits of iron ore, when it is called *flosferri,* or the flower of iron.

f. **Cone in Cone**, fig. 6.—This structure is often met with in iron ores from the coal measures. It consist of a series of fibrous concentric conical masses, the points of the cones meeting together, or sometimes interlaced as shown in the figure.

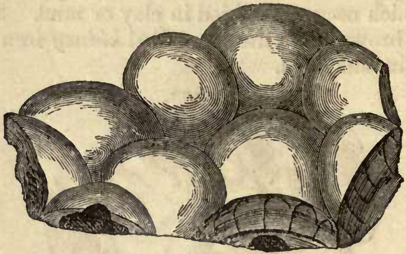

Fig. 4.—MAMMILLARY.

Fig. 5.—CORALLOIDAL. (From a Photograph.)

Fig. 6.—CONE IN CONE. (From a Photograph.)

g. **Stalactitic** (*icicle-shaped*), fig. 7.—*Chalcedony*, *calcite*, and *barytes* often occur in this form. Sometimes the stalactites are hollow, sometimes solid; but in stalactites of calcite and barytes, a cross-section almost always reveals a structure consisting of fibres radiating from the centre, and the same thing is visible in properly prepared slices of chalcedony, when examined under the microscope.

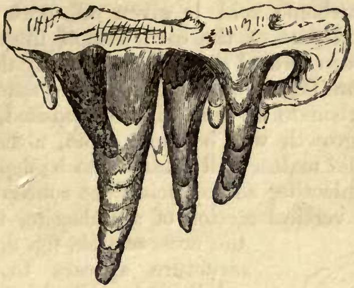

Fig. 7 — Stalactitic.

Fig. 8.—Vertical Section of a Stalactite of Calcite, showing successive layers of deposited matter. (From a Photograph).

10. It is probable that most, if not all, of the above-described imitative forms are the result of deposition from solution, at any rate this is known to be the case in some instances. Thus, stalactites of calcite, or carbonate of lime, may be seen in process of formation in caverns in most limestone districts, and they are very frequently formed under bridges or tunnels which have been built with lime mortar. The process of formation is as follows: rain water containing carbonic acid in solution in filtering through limestone, mortar, or other material containing carbonate of lime dissolves a part of it. On becoming again exposed to the air drop by drop, part of the carbonic acid is given off, part of the water evaporates, and part of the carbonate of lime is deposited. A stalactite once formed the water naturally descends to its lower end before falling off, and it is there that the greatest amount of carbonate of lime will be deposited, and in this direction its growth will be most rapid, although a small quantity of solid matter will continue to be deposited on the sides of the stalactite, so producing the concentric structure shown in the vertical section of a stalactite, fig. 8, and in the cross-section, fig. 9. The radial structure appears to be of later origin; it is really due to an incipient crystallization set up within the mass.

Fig. 9.—Cross-section on line A B, fig. 8, showing concentric and radial structure. (From a Photograph).

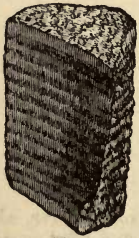

Fig. 10. — Fragment of Stalagmite from the floor of a Limestone Cavern, showing layers of equal thickness.

The water dropping from the stalactite will still contain some carbonate of lime in solution. This will be deposited on the ground beneath, when the conditions are favourable, forming what is known as *stalagmite.* A cross-section of stalagmite, however, will differ from that of a stalactite, owing to the tendency which the drops of water have to spread themselves out. If the supply of water be abundant, a sheet of stalagmite will be formed if only a little falls, a pillar of stalagmite will gradually rise towards the stalactite above; but in all cases the separate layers will be of about equal thickness throughout, as shown in fig. 10.

Many other substances besides carbonate of lime are thus deposited from solution. In the old workings of several Cornish tin and copper mines, the writer has frequently seen long stalactites of oxide of iron depending from the roof, and stalagmites of the same material rising from the floor to meet them. Stalagmites of malachite were seen in process of formation in the mines of Russia, by Sir Roderick Murchison.

11. The crystalline structure sometimes observable in the imitative forms already described, is probably the result of a secondary action of the crystallising forces, following the actual formation of the solid mineral. There are, however, other imitative forms which are merely irregular crystals or crystalline aggregates, and in the formation of which the crystallising forces appear to have been concerned from the first. These are the so-called *capillary* and *wiry* forms observable in *native silver*, the *mossy* and *leafy* forms seen in *native copper*, the *dendritic* markings of *oxide* of *manganese*, the reticulate groupings characteristic of *mountain leather*, and the *stellate* groups of crystals often met with in *stilbite* and other minerals. These will be further described in a future chapter.

CHAPTER III.

OF THE GENERAL PROPERTIES OF CRYSTALS.

12. Many minerals occur naturally in forms bounded by plane surfaces, having peculiar geometrical relations to each other. These are called "crystals," the plane surfaces are termed "planes" or "faces," the lines formed at the junction of any two such planes are "edges," and the points formed by the meeting of any three or more edges are called "solid angles."

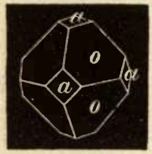

Fig. 11.

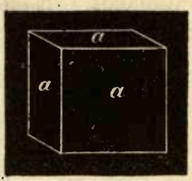

Fig. 12.

Every plane in a crystal has a definite inclination or slope in relation to every other plane, except such as may be parallel to it. These mutual inclinations are quite independant of the size or general form of the crystals, and they are constant for similar planes even in different crystals of the same mineral, as is shown by measurement with the goniometer.* Thus, if figs. 11 and 12 represent crystals of fluor, the planes *a a* will in each case be inclined 90° to each other, and the planes *o o* 109° 28′, notwithstanding the difference in their appearance and in the general aspect of the crystal. The mode of actual measurement is resorted to when the crystal form of any specimen is to be determined for the first time; but the geometrical relations of the planes are best understood by referring them to certain imaginary lines

---

* γωνία (*gonia*), an angle; μέτρον (*metron*), a measure.

termed axes, which are supposed to exist within every crystal.

To understand the higher branches of crystallography requires a good deal of mathematical knowledge and skill, but the attempt has been made to write the crystallographic portion of this volume in such a manner that a very moderate acquaintance with elementary geometry and with algebraic signs and formulæ, may suffice on the part of the student.

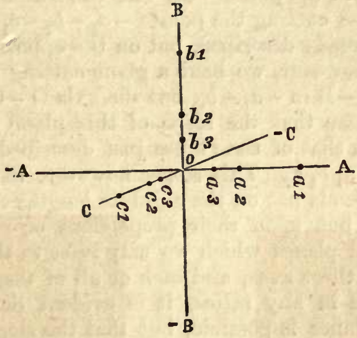

Fig. 13.

13. We have said that the planes of all crystals are *referred* to their axes. Fig. 13 will help the student to realise what is meant by this statement. Let A – A, B – B, C – C, represent three axes of a crystal, cutting each other in the centre, O. In the figure, the axes are drawn in perspective, but they are in this instance supposed to be of equal length, and at right angles to each other. The semi-axes OA, O – A, OB, O – B, OC, O – C, are called the parameters. Let us suppose one plane of the crystal to be so situated as to cut the three parameters OA, OB, OC, at their extremities A, B, C, which, it must be remembered, are equidistant from the centre. It is evident that such a plane will have a definate inclination or slope. Suppose, further, a plane to exist cutting the three semi-axes in the points a_1 b_1 c_1, which are also equally distant from the centre O. Such a plane will be smaller than that cutting the points

A, B, C, but it will be evidently parallel to it, since the distances Oa_1 Ob_1 Oc_1 are equal. A little consideration will show that whatever the absolute distances from the centre may be, so long as they are equal, no new slope or inclination is possible; the planes so situated will be parallel and similar, and any sign devised to express the slope of one will indicate the slope of all. A plane, however, cutting the points a_1 b_1 c_2 will have quite a different slope.

We will now suppose a plane to cut the semi-axes $O-A$, $O-B$, $O-C$, in the points $-A$, $-B$, $-C$. This plane will be parallel to one cutting the points $-a_1-b_1-c_1$; and also to the planes already described, but on the opposite side of the centre. If, however, we have a plane cutting the semi-axes $O-A$ and $O-B$ in $-a_1-b_1$, but the axis $O-C$ in the point $-c_2$, it is clear that the slope of this plane will be quite different from that of the planes just described, and parallel to the plane a_1 b_1 c_2. This slope, however, like the others, evidently depends not on the absolute lengths of the portions Oa_1 Ob_1 Oc_2, but upon their proportions or ratios, and so with all other planes which we may refer to the same axes. As there are three axes, and each or all of them may be cut at any points in any ratios, it is evident that an infinite number of planes is possible, but that the slopes of all are fixed so long as we know those ratios. Fortunately, in any particular mineral, the number of planes is limited by the fact that the ratios are always comparatively simple and not very numerous.

14. Elements of Crystals.—In most crystals the planes are referred to *three* axes, but in one large class they are sometimes referred to *four*. The axes may cut each other at right angles or at any other angles. The number and relative situation of the axes, and the ratios of the parameters, together constitute what are called the *elements* of a crystal.

15. Crystallographic Notation.—Many systems have been at different times devised for indicating the relations of the different planes to the axes, but of these it is only necessary for the student to be acquainted with three at present, those used by Professors Mitchell, Naumann, and Miller. A brief outline of Naumann's system is given in the "First Book of Mineralogy," forming one of this series of text-books, and some further explanations will be given hereafter as occasion may arise. The symbols adopted throughout this work in describing the various forms, are those of Professor Mitchell, except when the contrary is stated. They are modified from those used by Miller, and generally differ but little from them. Naumann's symbols will also be given in many cases.

In order to understand the symbols of Mitchell and Miller, we must refer to fig. 14. Let – A O A, – B O B, – C O C, represent three axes of a crystal cutting each other in the centre O. Different planes will cut these axes in different ratios; but in all crystals some planes will be of more importance than others, and these are regarded as belonging to primary forms.

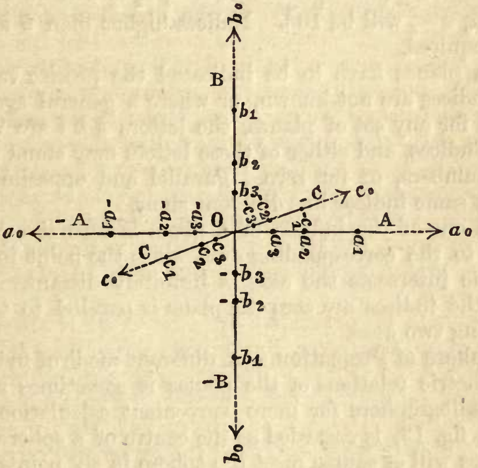

Fig. 14.

Suppose one such primary plane to cut the axes in the points a_1 b_1 c_1, then Oa_1 Ob_1 Oc_1 may be regarded as the parameters of the form in question. Now on the line – A O A, take $Oa_2 = \frac{1}{2} Oa_1$, $Oa_3 = \frac{1}{3} Oa_1$, and so on; making as many points as may be necessary towards O. Take, also, $Oa_{-1} = Oa_1$, $Oa_{-2} = Oa_2$, $Oa_{-3} = Oa_3$, on the other side of the centre. Further, suppose Oa_0 to exist by prolonging the line $-$A O A in both directions to any infinite distance. Determine similar series of points in $-$B O B, $-$C O C, as shown in the figure.*

All the planes of a given crystal will now be parallel to one or other of the planes passing through three of the points so determined.

16. In Professor Miller's system of Notation, the symbol 111 is used for any plane parallel to that cutting the axes in $a_1\ b_1\ c_1$, 122 for these parallel to $a_1\ b_2\ c_2$ 313, for $a_3\ b_1\ c_3$, and so on; the numbers 111, 122, 313, are termed *indices*. When any of the points referred to have negative signs, the corresponding indices have negative signs placed over them. Thus, the indices of a plane parallel to $a_{-1}\ b_2\ c_2$ will be $\bar{1}22$, and of $a_{-1}\ b_0\ c_{-3}$ will be $\bar{1}0\bar{3}$. Indices higher than 6 are very rarely required.

When planes have to be indicated the precise values of whose indices are not known, or where a general symbol is required for any set of planes, the letters $h\ k\ l$ are used as general indices, and either of these letters may stand for any whole numbers, or for zero. Parallel and opposite planes have the same indices but different signs.

When one of the indices of a plane is zero the plane is parallel to the corresponding axis, since the point in which the plane intersects the axis is infinitely distant. When two of the indices are zero the plane is parallel to the corresponding two axes.

17. Sphere of Projection.—A different mode of indicating the geometric relations of the planes is sometimes adopted by crystallographers for more convenient calculation. The centre *o*, fig. 13, is regarded as the centre of a sphere. The three axes will of course meet the sphere in six points, called the "poles of the axes." This sphere is called a "sphere of projection."

18. Normals.—From the centre O, radii are supposed to be drawn, meeting each plane perpendicularly. It is evident that the radii so originated will have fixed inclinations

---

* Many students will be greatly aided by taking three thin rods of wood, fastened together in the centre, and marking upon them with compasses the various points referred to in the text.

to each other. They are called "normals" to the planes, and the points in which they meet the sphere of projection are called the "poles" of the corresponding faces. A face and its pole may be indicated by the same symbol.

The angle included by any two normals is the *supplement* of that included by the two corresponding faces, so that it is easy to determine the angles of any two normals, when that of the corresponding faces is known, or *vice versa.* Thus, if the angle included by two planes be 110°, that of their normals will be 70°.

19. **Zones.**—It frequently happens that several faces of a crystal intersect each other, or would do so if they were produced until they met, so that the intersections form parallel lines. Such a series of faces is called a "zone." The normals of the several faces in a zone lie in one plane, called the "zone-plane," and the poles all lie in a great circle of the sphere of projection, called the "zone-circle." A line passing through the centre of the zone-plane, and cutting it at right angles, will be the "zone-axis." The zone-axis is parallel to all the faces of the zone. A face may be common to two or more zones, when its normal will coincide with the intersections of the several zone-planes.

20. **A Form** in crystallography is a figure bounded by a series of planes, having similar indices, differing only in their signs. Forms may be indicated by the symbol of any one of their faces. **Holohedral**[*] or "pleno-tesseral" forms are those in which the full series of planes having given indices are present. **Hemihedral**[†] or "semi-tesseral" forms are those in which only alternate faces or groups of faces are present. In **Tetartohedral**[‡] forms only one-fourth the full number of faces is present.

21. **Combinations.**—Any figure bounded by planes belonging to more than one form, is called a "combination." Thus, fig. 15 is a form called the octahedron ; fig. 16 is the form known as the cube. In figs. 17 and 18, which are said to be combinations of the cube and octahedron, the planes of both forms appear, and are indicated by corresponding letters.

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[*] ὅλος (*holos*), whole ; ἕδρα (*hedra*), a seat or plane.

[†] ἥμι (*hēmi*), half ; and ἕδρα.

[‡] τεταρτος (*tetartos*), fourth ; and ἕδρα.

These figures serve also to illustrate the differences in appearence which may exist when the same planes are more or less developed.

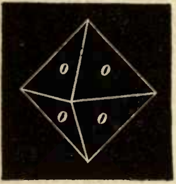

Fig. 15.

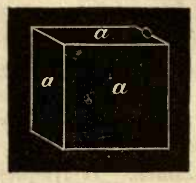

Fig. 16.

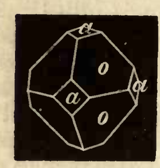

Fig. 17.

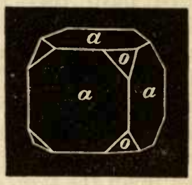

Fig. 18.

22. Systems of Crystal Forms.—It is usual to group all crystals under six systems, which have been severally named as under. The first of these names is that which will be adopted throughout in this work :—

1. **Cubical,** (*Octahedral, Tesseral, Tessular, Regular, Monometric,* etc.)
2. **Tetragonal,** (*Pyramidal,* 2 *and* 1 *axial, Dimetric,* etc.)
3. **Rhombic,** (*Prismatic, Orthotype,* 1 *and* 1 *axial, Trimetric,* etc.)
4. **Oblique,** (*Monoclinic, Hemiorthotype,* 2 *and* 1 *membered,* etc.)
5. **Anorthic,** (*Triclinic, Double Oblique, Anorthotype,* 1 *and* 1 *membered*).
6. **Hexagonal,** (*Rhombohedral,* 3 *and* 1 *axial* etc.)

The elements of the six systems (see Art. 14) are as follows :—

Cubical.—Three axes at right angles to each other, the axes (consequently the parameters or semi-axes) equal in length. As the axes are equal to each other, and similarly related in all cubical minerals, the "elements" are said to be "fixed."

Tetragonal.—Three axes at right angles. Two equal to each other, called *lateral.* The third or *principal* axis is variable; in some pyramidal minerals it is longer, in others shorter than the laterals. There is consequently one "variable element" in this system, viz., the proportion existing between the length of the "principal" and "lateral" axes.

Rhombic.—Three axes at right angles. All unequal in length, and the relative lengths varying in different minerals. One is selected as the *principal,* the others are called *lateral.* The longer lateral axis is the "macro-diagonal,"[*] the shorter the "brachy-diagonal."[†] Thus there are two variable "elements" in this system, viz., the ratios respectively of the "macro" and "brachy" diagonals to the principal.

Oblique.—Three axes, two at right angles, the third inclined at different angles in different systems; relative lengths variable in different minerals and usually all unequal. One of the two which are at right angles is taken for "principal," that at right angles with it is termed the "ortho-diagonal,"[‡] that which is inclined is the "clino-diagonal."[§] There are consequently three variable "elements" in this system, viz., the ratios of two axes to the third, and the inclination of the "clino-diagonal" to the "principal."

Anorthic.[||]—Three axes: all variable in length and usually unequal; all inclined at different angles. Thus there are four variable "elements" in this system, viz., the ratios of two axes to the third, and their inclinations to each other. Either of the axes may be taken as principal, when the other two will be lateral. The longer lateral may be termed "macro-diagonal," the shorter "brachy-diagonal" as in the rhombic system.

Hexagonal.—Four axes: three *lateral—equal—lying in one plane,* and inclined to each other 60°; the fourth is principal, at right angles to the three lateral, of different length; sometimes longer, sometimes shorter. This is the

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[*] *μαϰϱος* (*makros*), great.

[†] *βϱαχυς* (*brachus*), short.

[‡] *οϱθος* (*orthos*), right or straight.

[§] *ϰλινη* (*cline*), inclined.

[||] *α* (*a*), without, and *οϱθος.*

only variable element in the system. Professor Miller refers hexagonal or "rhombohedral" crystals to a system of three axes of equal length, and equally inclined to each other, the actual inclination varying with different substances. This mode is more convenient for calculations in the higher branches of crystallography, but it does not so clearly represent to the non-mathematical student the relations of the various forms to each other, so that on the whole the ordinary mode of referring the forms to a system of four axes, is preferred on the present occasion.

CHAPTER IV.

REPRESENTATION OF CRYSTAL FORMS.

23. Figures of Crystals.—The most common mode of representing crystal forms on plane surfaces, is by what is known as "isometrical" or "parallel" perspective. This does not differ from ordinary perspective, except that the vanishing points are supposed to be infinitely distant. In other words, lines which are parallel are always drawn parallel and not converging, and equal lines which make equal angles with the plane of projection (the paper), are made equal in length.

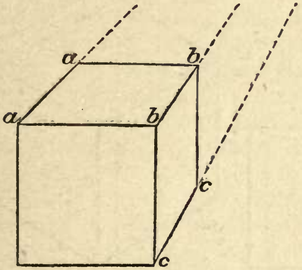

Fig. 19.—Cube in Ordinary Perspective.

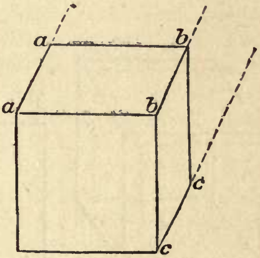

Fig. 20.—Cube in Parallel Perspective.

The difference between parallel and ordinary perspective is shown in figs. 19 and 20. In fig. 19 the cube is drawn in ordinary perspective, and the parallel and equal lines *c c*, *b b*, and *a a*, are seen to be converging; and although they form equal angles with the plane of projection, are drawn of unequal lengths. In fig. 20 the cube is drawn in parallel perspective, and the difference is very easy to be seen, for here the lines *a a*, *b b*, *c c*, are evidently parallel and equal in length.

Crystals are often drawn, as in fig. 21, as if transparent, but in complex crystals the multiplicity of lines is very confusing, and even in simple forms the advantage is not great, so that crystals are more generally drawn as if opaque.

24. Positions of Crystals.—Drawings of crystals differ much according to the position in which the axes are placed with reference to the plane of projection. Thus, in addition to the representations of the cube given in figs. 16, 19, 20, 21, the cube may be drawn as in fig. 22, with two axes parallel to the plane of projection, when it appears as a simple square, or with the three axes equally inclined, as in fig. 23. This latter figure is said to be in *isometrical* perspective,* because *all* equal lines are here drawn equal in length. Of these different modes, that shown in fig. 16 is usually preferred for crystals belonging to the cubical system, and this mode will be hereafter adopted in the present work. This is a projection on a plane parallel to one face of the cube, that marked 010 by *Miller*, by parallel lines which are not perpendicular to that face.

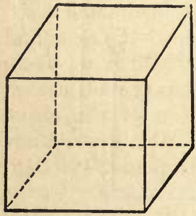
Fig. 21.

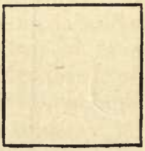
Fig. 22.

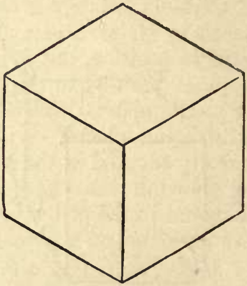
Fig. 23.

A somewhat similar projection is often adopted for crystals belonging to the tetragonal or pyramidal system, and for the rhombic or prismatic system; the principal axis being placed vertically and parallel to the plane of projection. Another mode is to place the principal axis perpendicular to the plane of projection or parallel to the plane 001 of *Miller*, and O P of *Naumann*. The advantage of this mode is, that

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* From ἴσος (*isos*), equal, and μέτρον (*metron*), a measure.

it shows the equality of the two lateral axes in the tetragonal system, and the ratios of the macro and brachy-diagonals in the rhombic system. By the ordinary mode of representation the crystals belonging to these two systems may readily be confounded ; thus, the tetragonal pyramid, fig. 24, may easily be mistaken for the rhombic pyramid, fig. 25, or *vice versa.* Figs. 26 and 27 show the other mode of projecting the same pyramids; and it will be seen that the distinction between the two systems is now very plain. Both modes have their advantages, however, and both will be occasionally adopted hereafter.

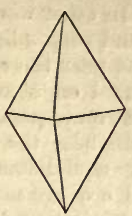
Fig. 24.

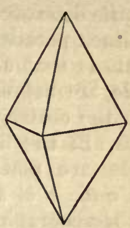
Fig. 25.

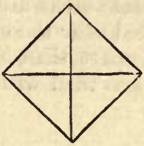
Fig. 26.

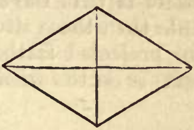
Fig. 27.

Crystals belonging to the oblique system are often drawn so as to show as many planes as possible, without much regard to position, but it is generally better to project them on a plane parallel to the clino-diagonal and the principal axis, or to the plane 010 *Miller,* $[\infty P \infty]$ *Naumann,* the principal axis being placed vertically. This mode, which we have usually adopted in the succeeding chapters, has the advantage of showing the exact amount of inclination of the clino-diagonal to the principal. In the anorthic system the crystals are projected on a plane at right angles to the planes 100,010, of *Miller,* or $\infty\bar{P}\infty$ $\infty\breve{P}\infty$, of *Naumann.*

In the hexagonal system the plane of projection is either parallel to the principal axis or parallel to the basal plane 111 *Miller,* O P *Naumann.*

25. Crystal Maps.—These are representations on plane surfaces of the sphere of projection, upon which are shown the poles of the several faces. The *orthographic* projection of the sphere is sometimes used, but the *stereographic* projection is preferred, because it has the advantage of representing all great circles of the spheres by straight lines or arcs of circles. In the orthographic projection the sphere is supposed to be viewed with the eye placed opposite the centre, but at an *infinite* distance. In other words, it is projected upon a plane by lines parallel and perpendicular to it, as in fig. 28*a*; the result is that areas near the circumference of the projected circle are represented on a much *smaller* scale than those near the centre, and consequently much distorted as to form. Thus, in the figure 28*a*, the points *a b c d* on the semicircle are plainly equi-distant, but of their projections *a′ b′ c′ d′*, *a′ b′* and *c′ d′* are nearer together than *b′ c′*. In the stereographic projection the lines converge to a point opposite the centre, but at a distance from the plane of projection equal to the radius of the sphere, as in fig. 28*b*. The result is that the outside areas are represented on a *larger* scale than those situated near the centre; thus, *a′ b′* and *c′ d′* are projected farther apart than *b′ c′*; but the distortion of parts is on the whole less than with the former projection.

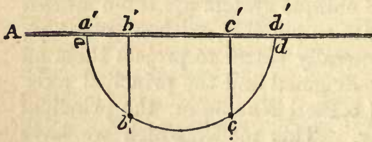

Fig. 28*a*.

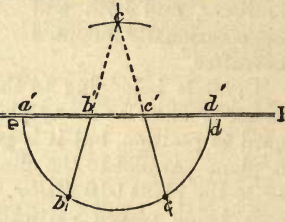

Fig. 28*b*.

A good idea of the principle of *orthographic* projection may be obtained by supposing a *hollow* hemisphere viewed through a sheet of glass, from an infinite distance, so that lines coming from the interior surface may meet the glass screen as parallel lines. If a tracing of the various objects on the surface of the sphere be made upon the glass, the result will be an *orthographic* projection of the hemisphere.

If now, through a similar screen, a *hollow* hemisphere be viewed, which touches the glass at its circumference, the eye being placed at a distance from the glass equal to the radius of the sphere, will now look into the hemisphere, and if the objects be traced where they appear upon the screen, the result will be a *stereographic* projection of the hemisphere.

Crystal maps so produced convey a good deal of information which can hardly be represented in the ordinary perspective figures, and they greatly facilitate calculations in the higher branches of crystallography.

26. Zone-circles.—These maps are of great service in illustrating the relative situations of the *zone-circles,* as is shown in fig. 29, which is a representation of the principal zones of the cubical system. The construction of the figure is evident: $o_1\ o_2\ o_3$, etc., are the poles of the octahedral faces; $a_1\ a_2\ a_3$, etc., those of the faces of the cube; and $d_1\ d_2\ d_3$, those of the rhombic dodecahedron. The zones are represented by the lines, and it will be seen that the planes a_1, etc., are common to no fewer than four zone-circles.

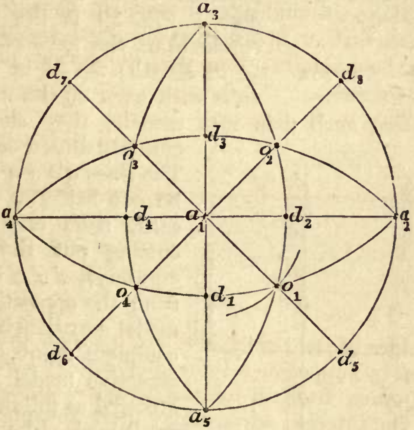

Fig. 29.

27. Sphere of Projection.—The situation of the poles on the "sphere of projection" may be realised by considering the figure as an ordinary school globe. The points a_3 and a_5 will then represent the north and south poles respectively, and the circle $a_4\ d_4\ a_1\ d_2\ a_2$ the equator. If the line joining the poles be regarded as the meridian of Greenwich, d_2 will be longitude 45° E., and d_4 longitude 45° W. The points $d_7\ d_3\ d_8$ and $d_6\ d_1\ d_5$, will be respectively in 45° N. latitude, and 45° S. latitude. In this manner it is quite clear that the latitude and longitude of all normals (Art. 18) may be readily laid down, and their relations at once determined by means of spherical trigonometry. The angles of the normals once known, those formed by the various planes with each other are the supplements of these angles.

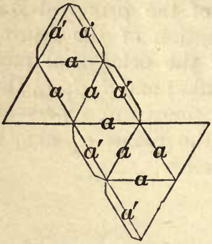

Fig. 30.—Net for Octahedron.

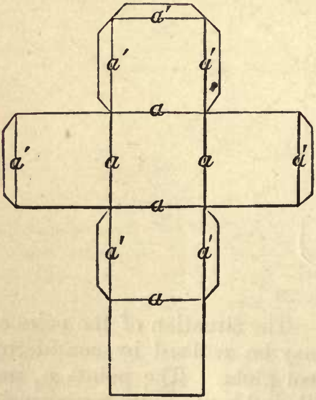

Fig. 31.—Net for Cube.

28. Crystal Nets.—In the absence of ordinary models the student will find much advantage in the construction of models of cardboard, by means of what are known as *crystal nets.*[*] For this purpose the surface of the required figure is drawn upon paper or cardboard, this is then folded into the required form, and fastened with glue. Fig. 30 is the net for an octahedron, the axes of which are $\frac{1}{2}''$ in length; fig. 31 is a, net for a cube with axes of the same length. In converting such nets into models, they should be accurately drawn on cardboard. The lines *a a a a* should then be cut half-way through the card, from one side (after cutting out the figure accurately), *a' a' a'* half through from the opposite side. The model may then be folded into complete figure. A very instructive model may be constructed as follows: a net of cardboard, like fig. 30, is carefully cut out, folded, and gummed, into a complete octahedron; a cube of glass is now prepared, the sides being made of $\frac{1}{2}''$ squares of thin glass. This is built up outside the octahedron, as in fig. 32. This compound figure shows the situation of the primary

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[*] A complete set of "nets" for the simple forms of crystals has been prepared by Mr. J. B. Jordan, of the Mining Record Office.

octahedron within the cube, and the situation of the axes in both figures. A similar representation of the rhombic dodecahedron within the cube is given in fig. 33.

Occasionally similar faces of crystals are indicated by a similar mode of shading, and this plan has been adopted by Mr. Rutley. A less confusing mode is to indicate the faces by their proper symbols, or else by letters.

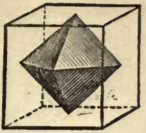

Fig. 32.

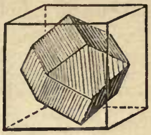

Fig. 33.

CHAPTER V.

FORMS (*Continued*)—HOLOHEDRAL FORMS OF THE CUBICAL SYSTEM.

29. In this system the axes are at right angles, and the parameters equal. The several forms in this system are 13 in number, 7 being holohedral, having the general sign $h\ k\ l$ in Miller's system; 4 hemihedral, with inclined faces, having the general sign $\kappa\ h\ k\ l$, and 2 hemihedral, with parallel faces, with the general sign $\pi\ h\ k\ l$. In the present chapter the 7 holohedral forms will be defined.

30. **The Octahedron** (*Regular Octahedron*, fig. 34).—Symbol, 111 *Mitchell* and *Miller*; O *Naumann*. This is the simplest form in the system, as the three parameters are not multiplied or divided in any way, but are met at normal distances from the centre of the crystal by a series of planes which together compose the complete form, the axes joining the solid angles.

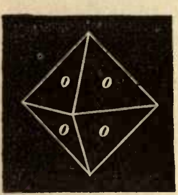

Fig. 34.

Fig. 35.

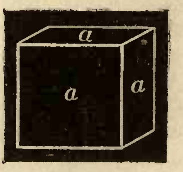

Fig. 36.

The regular octahedron is bounded by eight equal equilateral triangles, the planes forming with each other angles of 109° 28′,* the normals therefore being inclined 70° 32′. In fig. 35 the proper modifications of the general sign 111

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* 109° 27′ 3″, more exactly.

are placed over the indices of the four faces shown. The complete symbol of the form will be 111. $11\bar{1}$. $\bar{1}1\bar{1}$. $\bar{1}11$. $1\bar{1}1$. $1\bar{1}\bar{1}$. $\bar{1}\bar{1}\bar{1}$. $\bar{1}\bar{1}1$.

The face 111 corresponds with a plane cutting the points A.B.C, or a_1 b_1 c_1, or any other parallel plane in fig. 13. Similarly, the face $11\bar{1}$ corresponds with A C – B, or any parallel plane; and so on with the other faces.

Naumann's symbol is obtained by taking the initial letter of the word octahedron to represent the primary form of the system. The complete symbol might be written OOO, to harmonise better with the symbols of the other forms, but it is always contracted to O. It should be observed that Naumann's sign applies to the whole form, and affords no means of distinguishing between the several faces, unlike Miller's more scientific system, which supplies a general symbol capable of modification, so as to indicate every face of the form separately.

We may also remark in this place, that the order of the three indices of Miller's symbols never varies, the first always refers to the axis A – A, the second to the axis C – C, the third to the axis B – B, figs. 13, 14.

31. The **Cube** (*Hexahedron*, fig. 36).—Symbol, 1∞∞ *Mitchell*, 100 *Miller*, ∞O∞ *Naumann*. This form is bounded by six equal squares, which consequently make angles with each other, of 90°, and of course the normals do also. Each face meets one parameter at its normal distance (1) from the centre, and is parallel to the two others, or as may be said, cuts them at an infinite distance, *i.e.*, not at all. This fact is expressed by *Miller's* symbol, 100, as well as by *Mitchell's* 1∞∞, where the sign ∞ stands for infinity, and *Naumann's* ∞O∞, where ∞ stands for infinity, and O for the parameter cut at its normal distance from the centre. As already mentioned, Naumann's symbol applies to the whole form, so that the order of its several portions is quite unimportant. It might indeed be written ∞∞O or O∞∞, as the only fact to be expressed is, that the planes each cut one parameter at the distance (1), and are parallel to the other two. The symbol, however, is always used as written above, ∞O∞.

32. The **Rhombic Dodecahedron**, fig. 37.—Symbol,

11∞ *Mitchell,* 101 *Miller,* ∞OO *Naumann,* contracted to ∞O. This form is bounded by twelve equal rhombs, its faces making angles with each other of 120°, measured over the edges, the normals being inclined 60°. The ratio of the diagonals of the rhombs is as $1 : \sqrt{2}$ (1 to the square root of 2). The axes join the opposite four-sided solid angles, and each plane cuts two axes at the normal distance (1), and is parallel to the third.

The rhombic dodecahedron is the **Granatoid** of *Haidinger,* and the **Granatohedron** of *Weiss;* it is a characteristic form of garnet.

Fig. 37.

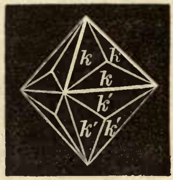


Fig. 38.

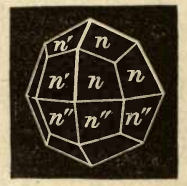


Fig. 39.

33. The **Three-faced Octahedron** (*triakis-octahedron,* fig. 38).—Symbols, 11*m* *Mitchell, h h k Miller, m*OO, contracted to *m*O *Naumann.* It is bounded by twenty-four equal isosceles triangles, and the axes join the opposite eight-sided solid angles. Each plane cuts two axes at equal and normal distances (1) from the centre; but the third is cut at a distance greater than (1), and less than (∞). The third parameter sometimes only a little exceeds, sometimes very greatly exceeds the other two, consequently the angles measured over the edges, from face to face, and the normals of these, are different for different crystallised substances.

The variable quantity more than (1), and less than (∞), is indicated by the letter *m,* so that the symbol of each face, or of the complete form, is as already given, 11*m.* The three-faced octahedron is like an octahedron upon which three planes have been built up over each plane of the original, hence the name. The thicker line around one group of planes in the figure, shows the edges of the fundamental octahedron. An infinite number of varieties of this form might exist, since *m* may be any quantity more than 1, and less than infinity. In fact, however, only 7 different values of m have been observed in natural crystals. The limits of the form are evidently the octahedron, as m becomes smaller and finally equals 1, and the rhombic dodecahedron as m becomes greater, and finally equals ∞. The three-faced octahedron was called **Galenoid** by *Haidinger*, because it is a common form of galena. It also occurs frequently in pyrites, and, with curved faces, in the diamond.

34. The **Deltohedron** (*twenty-four faced trapezohedron* or *icositetrahedron*, fig. 39).—Symbols, $1mm$ *Mitchell*, $h\,k\,k$ *Miller*, mOm *Naumann*. This form is bounded by twenty-four equal trapeziums or deltoids, and the axes join the opposite four-sided solid angles. Each plane cuts one parameter at normal distance (1), and the other two at distances mm, greater than (1), but less than (∞), and equal to each other. As m approaches (1), the form approaches the octahedron; as m increases towards (∞), it approximates to the cube. These forms are therefore the limits of the deltohedron. Of course the angles of faces and normals vary with different substances. It is the **Leucitoid** of *Haidinger*, being a characteristic form of leucite.* It also occurs frequently in garnet.

Fig. 40.

Fig. 41.

35. The **Four-faced Cube** (*tetrakis-hexahedron*, fig. 40).—Symbols, $1m\infty$ *Mitchell*, $h\,k\,o$ *Miller*, ∞Om *Naumann*. It is bounded by twenty-four equal isosceles triangles, and the axes join the opposite four-sided solid angles. Each plane cuts one parameter at normal distance, is parallel to a second, and cuts the third at a variable distance (m) greater than (1) and less than (∞). The limits of the form are the cube, when m equals ∞, and the rhombic dodecahedron

---

* It will be seen in a later chapter that there are reasons for supposing that leucite is not a member of the cubical system.

when it equals 1. As *m* is variable, the angles of faces and normals are different in the different varieties of forms.

The four-faced cube was called **Fluoroid** by *Haidinger*, because of its frequent occurrence in the mineral fluor.

36. The Six-faced Octahedron (*hexakis-octahedron*, fig. 41).—Symbols, 1*mn* *Mitchell*, *h k l* *Miller*, *m*O*n* *Naumann*. This form is bounded by forty-eight equal and similar scalene triangles, the axes join the opposite eight-sided solid angles. Each plane cuts one parameter at its normal distance (1), a second at a distance (*m*) greater than (1) and less than infinity, and a third (*n*) greater than (*m*) but still less than infinity. When *n* equals *m* the deltohedron results; when *n* becomes ∞ the four-faced cube is produced. These two forms are therefore the limits of the six-faced octahedron. It may be considered the most perfect form of the cubical system, as it contains all the possible arrangements of $\pm h \pm k \pm l$ taken three at a time. It is a characteristic form of the diamond, and was for this reason called **Adamantoid** by *Haidinger*.

37. Poles of the Cubical System.—The projection of the poles of the "normals" to the several faces of the cubical system are given in fig. 42, which is an octant of the sphere of projection given in fig. 29; *o* is a pole of the octahedron; *a a* are poles of cubical faces; *d d* poles of the rhombic dodecahedron. The poles of the three-faced octahedron are variable in situation, but fall on *o d*; those of the deltohedron on *o a*, of the four-faced cube on *a d*, and of the six-faced octahedron within the triangles.

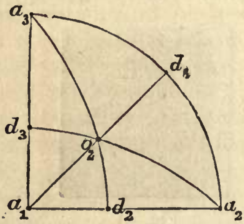


Fig. 42.

CHAPTER VI.

FORMS (*Continued*)—HEMIHEDRAL FORMS OF THE CUBICAL SYSTEM.

38. The meaning of the term "hemihedral" has already been explained (*See* Art. 20). The hemihedral forms of the cubical system are six in number; four having inclined faces, and two parallel faces. The hemihedral forms with inclined faces are distinguished by the general symbol $\kappa\, h\, k\, l$; those with parallel faces by the general symbol $\pi\, h\, k\, l$.

39. The **Tetrahedron,** fig. 43.—Symbol, $\frac{111}{2}$ *Mitchell*, $\kappa\, 111$ *Miller*, $\frac{O}{2}$ *Naumann*. This form is bounded by four equal equilateral triangles, which are inclined to each other at angles of 70° 32′ (nearly), the normals being inclined 109° 27′ (nearly). Its faces correspond in situation and relation to the axes, with four alternate faces of the octahedron, consequently the sign is the same, but written with the sign of division by two, thus, $\frac{111}{2}$ to indicate their hemihedral character. In Miller's system this is sufficiently indicated by the sign κ. The axes join the central points of opposite edges.

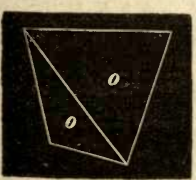


Fig. 43.

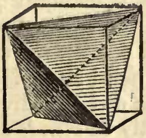


Fig. 44.

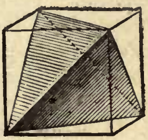


Fig. 45.

The tetrahedron may be very simply derived from the cube, as shown in figs. 44 and 45, where 45 is negative and 44 positive. If a crystal be simply a perfect tetrahedron, it cannot properly be described as either positive or negative; but occasionally faces of both the tetrahedrons occur in the same crystal developed to a different extent. In such cases the negative faces are indicated by prefixing the negative sign, thus, $-\frac{111}{2}$. Similar positive and negative forms exist for the other hemihedral forms. It is evident that the octahedron may be regarded as a combination of the positive and negative tetrahedrons equally developed. The tetrahedron occurs in *fahlerz* (hence called **Tetrahedrite**) and in *blende.*

40. The **Trigonal Dodecahedron** (three-faced tetrahedron), fig. 46.—Symbol, $\frac{1mm}{2}$ *Mitchell*, κ *h k k Miller*, $\frac{mOm}{2}$ *Naumann.* This form which is bounded by twelve equal isoceles triangles is the hemihedral form of the deltohedron (fig. 39); its planes corresponding with alternate groups of three faces of that figure. The axes join the central points of the longer edges. The limits of the form are the tetrahedron, when *m* equals 1, and the cube when *m* equals ∞. It is a form of frequent occurrence in *blende* and *fahlerz.*

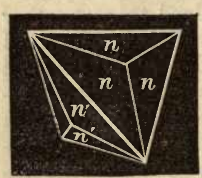


Fig. 46.

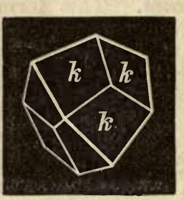


Fig. 47.

Fig. 48.

41. The **Deltoid Dodecahedron** (twelve-faced trapezohedron), fig. 47.—Symbols, $\frac{11m}{2}$ *Mitchell*, κ *h h k Miller*, $\frac{mO}{2}$ *Naumann.* This form is bounded by twelve equal deltoids or trapezoids; its faces correspond with alternate groups of faces of the three-faced octahedron (fig. 38). The axes join the opposite four-sided solid angles. Its limits are the tetrahedron and the rhombic dodecahedron, as *m* approaches 1 or ∞. It occurs frequently in *blende* and *fahlerz.*

42. The **Six-faced Tetrahedron** (*hexakis tetrahedron*), fig. 48.—Symbols, $\frac{1mn}{2}$ *Mitchell*, κ *h k l Miller*, $\frac{mOn}{2}$ *Naumann.* This form is bounded by twenty-four equal scalene triangles, which correspond with alternate groups of six of the six-

faced octahedron (fig. 41). Its axes join the opposite four-sided solid angles. The limits of the form are the trigonal dodecahedron and the deltoid dodecahedron. Good examples occur sometimes in *boracite.*

43. In the four hemihedral forms just described, no face is parallel to any other face. They are often found in natural crystals combined with some of the forms previously described, but never with the two forms, with parallel faces, now to be described.

44. The **Pentagonal Dodecahedron,** fig. 49.—Symbols, $\frac{1m\infty}{2}$ *Mitchell,* π *h k o Miller,* $\frac{\infty O m}{2}$ *Naumann.* This form is bounded by twelve equal pentagons, corresponding in situation with alternate planes of the four-faced cube. The axes join the central points of the opposite longer edges. The limits of the form are the rhombic dodocahedron and cube, as *m* equals 1 or ∞. It is sometimes called **Pyritoid,** because it is a characteristic form of iron pyrites and cobalt pyrites (cobaltite).

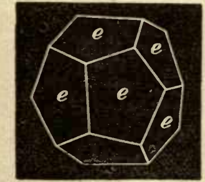


Fig. 49.

Fig. 50.

45. The **Trapezohedron** (irregular twenty-four faced trapezohedron), fig. 50.—Symbols, $\left[\frac{1mn}{2}\right]$ *Mitchell,* π *h k l Miller,* $\frac{mOn}{2}$ *Naumann.* This figure is bounded by twenty-four equal trapeziums. The axes join the opposite *equi-angular* four-sided solid angles. Like the six-faced tetrahedron, fig. 48, it is the hemihedral form of the six-faced octahedron, fig. 41; but it is derived according to a different law. In the former the planes $\frac{1mn}{2}$ correspond with alternate *groups* of the planes 1*mn*, in the latter with *alternate* planes 1*mn*. The *slopes* of the planes, however, correspond in both cases with those of the six-faced octahedron; to distinguish this figure from the six-faced tetrahedron, fig. 48, the sign is written in brackets, thus, $\left[\frac{1mn}{2}\right]$ *Mitchell,* or $\left[\frac{mOn}{2}\right]$ *Naumann.*

The limits of form for the cubical system are as follows:—

a. The octahedron, when m and $n = 1$.

b. The cube, when m and $n = \infty$.

c. The rhombic dodecahedron, when $m = 1$ and $n = \infty$.

d. The three-faced octahedron, when $m = 1$ and n is more than 1 and less than ∞.

e. The deltohedron, when m and n are equal, more than 1, and less than ∞.

f. The pentagonal dodecahedron, when m is more than 1 and less than ∞, while n becomes ∞.

CHAPTER VII.

FORM (*Continued*)—COMBINATIONS OF FORMS IN THE CUBICAL SYSTEM.

46. Of the thirteen distinct forms of crystals described in the preceding chapters, the planes of several are often combined in one crystal, so as to produce what are called modified forms or *combinations.* Such modified forms are indeed much more commonly met with in nature than are the simple forms themselves.

In the figures illustrating combinations, the same letters always indicate similar planes, so that the student will have little difficulty in tracing the relations of the various forms.

47. Combinations of Fixed Holohedral Forms with each other.

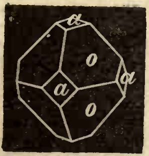


Fig. 51.

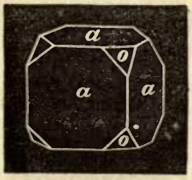


Fig. 52.

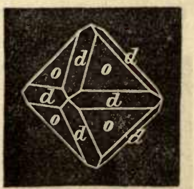


Fig. 53.

Octahedron and Cube, figs. 51 and 52. The planes *o* are those of the octahedron, *a* those of the cube. It will be seen that the *slopes* or *inclinations* of the corresponding planes are alike in both figures; they have the same situation with respect to the axes, and the same inclinations to each other. The octahedral planes in fig. 51, however, are not triangles but irregular hexagons, nor are the cubical planes square in fig. 52, as in the simple forms. From this we learn, that, except in the simple forms, the shape of the plane is quite unimportant, while its slope or inclination, as referred to the axes, is really its essential character.

The signs used to denote combinations are those of the simple forms which enter into the combination, placed one after the other; those of the larger planes first. The sign of fig. 51 will therefore be 1.1.1, 1. ∞. ∞; that of fig. 52, 1. ∞. ∞, 1.1.1; the cubical sign being in this second instance placed first because the cubical faces are the largest.

Octahedron and Rhombic Dodecahedron, figs. 53 and 54, the dodecahedral planes being indicated by the letter *d*. The sign of the combination will be, for fig. 53, 1.1.1, 1.1. ∞; for fig. 54, 1.1. ∞, 111.

Fig. 54.

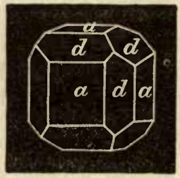


Fig. 55.

Fig. 56.

Cube and Rhombic Dodecahedron, fig. 55, 1. ∞. ∞, 1.1.∞; fig. 56, 1.1. ∞, 1. ∞. ∞.

Cube, Octahedron, and Rhombic Dodecahedron, fig. 57, 1. ∞. ∞, 1.1.1, 11 ∞.

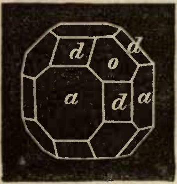


Fig. 57.

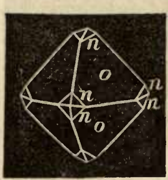


Fig. 58.

Fig. 59.

48. Combinations of variable with fixed Holohedral Forms.

The combinations above described are combinations of forms whose angles are fixed, the parameters being either 1 or ∞, so that no variable elements are introduced. We have now to describe combinations in which the parameters are sometimes variable, *m* or *n*, so that a great variety of forms is possible according to the values of those variables. The illustrations given apply to modifications in which m or n have medium values. The octahedral, cubical, and deltohedral planes are indicated as before by the letters o, a, and d, respectively, n indicates the planes of the deltohedron, k those of the three-faced octahedron, s those of the six-faced octahedron, and e those of the four-faced cube.

Octahedron and Deltohedron, figs. 58, 59, 60. In fig. 58 the octahedral planes are largely developed, so that the sign will be 111, $1mm$. In fig. 59 the deltohedral planes are larger, and the sign will be reversed. Fig. 60 is a peculiar form, having its planes about equally developed so as to produce a figure having a quite different aspect, with thirty-two triangular faces. The triangles o are equilateral, the others are usually isosceles. The sign may be written either way. A figure of very similar general appearance, but fewer planes, may result from a peculiar development of the octahedron and pentagonal dodecahedron, as will be shown further on (fig. 78).

Octahedron and Three-faced Octahedron, fig. 61, 111, $11m$; fig. 62, $11m$, 111.

Octahedron and Six-faced Octahedron, fig. 63, 111, $1mn$; fig. 64, $1mn$, 111.

Octahedron and Four-faced Cube, fig. 65, 111, $1m\infty$, fig. 66, $1m\infty$, 111.

Cube and Deltohedron, fig. 67, $1\infty\infty$, $1mm$; fig. 68, $1mm$, $1\infty\infty$.

Cube and Three-faced Octahedron, fig. 69, $1\infty\infty$, $11m$; fig. 70, $11m$, $1\infty\infty$.

Cube and Six-faced Octahedron, fig. 71, $1\infty\infty$, $1mn$; fig. 72, $1mn$, $1\infty\infty$.

Cube and Four-faced Cube, fig. 73, $1\infty\infty$, $1m\infty$; fig. 74, $1m\infty$, $1\infty\infty$.

Rhombic Dodecahedron and Deltohedron, fig. 75, 11∞, $1mm$; fig. 76, $1mm$, 11∞.

Rhombic Dodecahedron and Three-faced Octahedron, fig. 77, 11∞, $11m$; fig. 78, $11m$, 11∞.

Rhombic Dodecahedron and Six-faced Octahedron, fig. 79, 118, $1mn$; fig. 80, $1mn$, 11∞.

Rhombic Dodecahedron and Four-faced Cube, fig. 81, 11∞, $1m\infty$; fig. 82, $1m\infty$, 11∞.

Fig. 60.

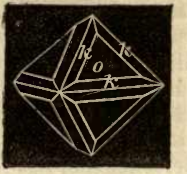


Fig. 61.

Fig 62.

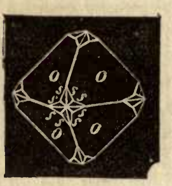


Fig. 63.

Fig. 64.

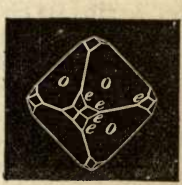


Fig. 65.

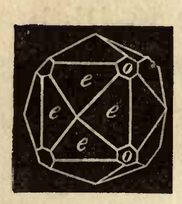


Fig. 66.

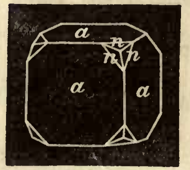


Fig. 67.

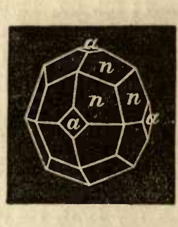


Fig. 68.

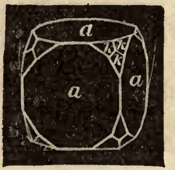


Fig. 69.

Fig. 70.

Fig. 71.

Fig. 72.

Fig. 73.

Fig. 74.

Fig. 75.

Fig. 76.

Fig. 77.

Fig. 78.

Fig. 79.

Fig. 80.

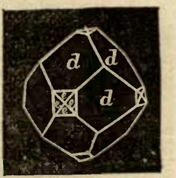


Fig. 81.

Fig. 82.

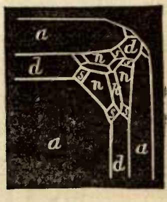


Fig. 83.

49. Complex Combinations.—A careful study of the foregoing examples will enable the student to read almost every possible holohedral combination in this system with facility, and it will be good practice for him if he will devise for himself other combinations than are here given. An example of the very complicated forms which are sometimes met with is given in fig. 83, which represents one corner of a crystal of fluor, from Mr. Turner's collection. The crystal had in all one hundred and fourteen faces. The signs of the faces are as follows:

$$\begin{array}{lll} a = 1\infty\infty & = 100 \\ d = 11\infty & = 110 \\ n = 1mm & = 133 \\ k = 11m & = 112 \\ s = 1mn & = 124 \end{array}$$

Actual measurement of the faces enabled Levy to assign the numerical values to m and n, given in the third column. A still more complicated form is shown in fig. 84, which represents a crystal of fluor from Beeralstone, in Devon, which formed part of Mr. Phillips' collection. This crystal if complete would have had three hundred and thirty-eight faces. One corner only is drawn in the figure.

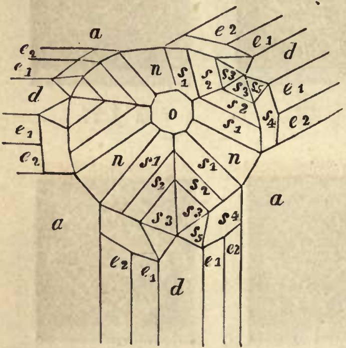


Fig. 84.

Here—

$$\begin{array}{ll} a = & 1\infty\infty \\ o = & 111 \\ d = & 11\infty \\ n = & 1mm \end{array}$$

$$\left.\begin{array}{l} e_1 = \\ e_2 = \end{array}\right\} 1m\infty,\ m \text{ having different values in each case.}$$

$$\left.\begin{array}{l} s_1 = \\ s_2 = \\ s_3 = \\ s_4 = \\ s_5 = \end{array}\right\} 1mn\ \ m \text{ and } n \text{ having different values in each case.}$$

50. Combinations of Holohedral with Hemihedral Forms.

Octahedron and Pentagonal Dodecahedron, fig. 85, 111, $\frac{1m\infty}{2}$; fig. 86, $\frac{1m\infty}{2}$, 111. In fig. 87 the two sets of planes are about equally developed, and the result is a figure bounded by eight equilateral triangles and twelve isosceles triangles, and having the same sign as fig. 85. It has a superficial resemblance to fig. 60, but has only twenty instead of thirty-two planes.

Octahedron and Irregular Trapezohedron, fig. 88, 1.1.1 $[\frac{1mn}{2}]$; fig. 89, $[\frac{1mn}{2}]$, 111.

Cube and Tetrahedron, fig. 90, $1\infty\infty$, $\frac{111}{2}$, and fig. 91, $\frac{111}{2}$, $1\infty\infty$.

Cube and Three-faced Tetrahedron, fig. 92, $1\infty\infty$, $\frac{1mm}{2}$; fig. 93, $\frac{1mm}{2}$, $1\infty\infty$.

Cube and Deltoid Dodecahedron, fig. 94, $1\infty\infty$, $\frac{1.1m}{2}$; fig. 95, $\frac{11m}{2}$, $1\infty\infty$.

Cube and Six-faced Tetrahedron, fig. 96, $1\infty\infty$, $\frac{1mn}{2}$; fig. 97, $\frac{1mn}{2}$, $1\infty\infty$.

Cube and Irregular Trapezohedron, fig. 98, $1\infty\infty$, $[\frac{1mn}{2}]$; fig. 99, $[\frac{1mn}{2}]$, $1\infty\infty$.

Cube and Pentagonal Dodecahedron, fig. 100, $1\infty\infty$, $\frac{1m\infty}{2}$; fig. 101, $\frac{1m\infty}{2}$, $1\infty\infty$.

Rhombic Dodecahedron and Tetrahedron, figs. 102 and 103, 11∞, $\frac{111}{2}$; fig. 104, $\frac{111}{2}$, -11∞.

Rhombic Dodecahedron and Deltoid Dodecahedron, figs. 105 and 106, 11∞, $\frac{1.1.m}{2}$; fig. 107, -11∞, $\frac{11m}{2}$.

Rhombic Dodecahedron and Three-faced Tetrahedron, fig. 108, 11∞, $\frac{1mm}{2}$; fig. 109, $\frac{1mm}{2}$, 11∞; fig. 110, $\frac{1mm}{2}$, 11∞. In the last figure the value of m is greater than in the other two, so producing a peculiarly-formed crystal.

Rhombic Dodecahedron and Six-faced Tetrahedron, fig. 111, 11∞, $\frac{1mn}{2}$; fig. 112, $\frac{1mn}{2}$, 11∞.

Rhombic Dodecahedron and Pentagonal Dodecahedron, fig. 113, 11∞, $\frac{1m\infty}{2}$; fig. 114, $\frac{1m\infty}{2}$, 11∞.

Rhombic Dodecahedron and Irregular Trapezohedron, fig. 115, 11∞, $[\frac{1mn}{2}]$; fig. 116, $[\frac{1mn}{2}]$, 11∞.

Fig. 85.

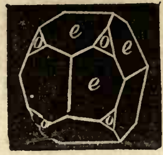


Fig. 86.

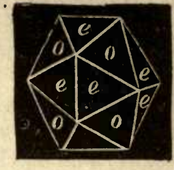
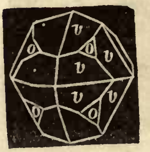


Fig. 87.

Fig. 88.



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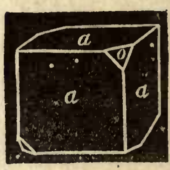


Fig. 90.

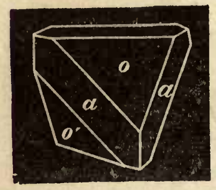


Fig. 91.

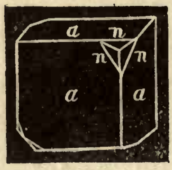


Fig. 92.

Fig. 93.

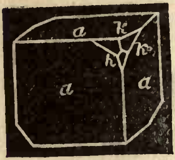


Fig. 94.

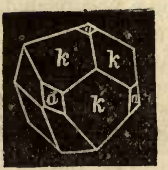


Fig. 95.

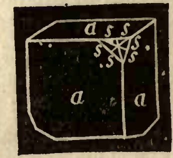


Fig. 96.

Fig. 97.

Fig, 98.

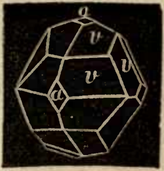


Fig. 99.

Fig. 100.

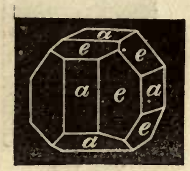


Fig. 101.

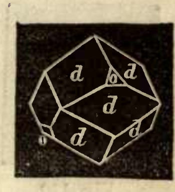


Fig. 102.

Fig 103.

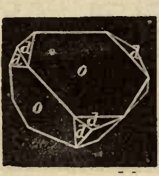
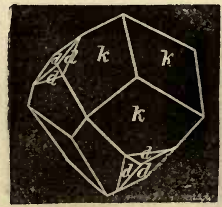


Fig 104.

Fig. 105.

Fig. 106.



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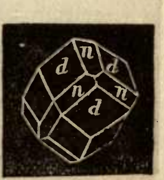

Fig 108.

Fig. 109.

Fig. 110.

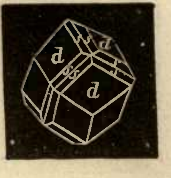

Fig. 111.

Fig. 112.

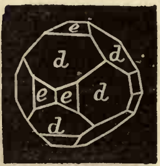

Fig. 113.

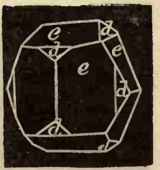

Fig. 114.

Fig. 115.

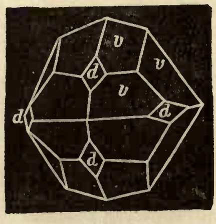

Fig. 116.

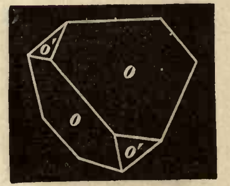

Fig. 117.

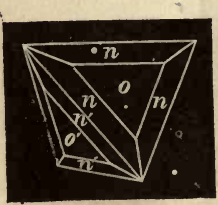

Fig. 118.

Fig. 119.

Fig. 120.

51. Combinations of Hemihedral Forms with each other.

Positive and Negative Tetrahedrons, fig. 117, $\frac{111}{2}, -\frac{111}{2}$. When the positive and negative planes become equal, the result is an octahedron, which may therefore be regarded as a combination of the two tetrahedrons.

Tetrahedron with Three-faced Tetrahedron, fig. 118, $\frac{111}{2}, \frac{1mm}{2}$; fig. 119, $\frac{1mm}{2}, \frac{111}{2}$; fig. 120, $\frac{111}{2}, -\frac{1mm}{2}$; fig. 121, $\frac{1mm}{2}, -\frac{111}{2}$; fig. 122, $\frac{1mm}{2}, -\frac{111}{2}, +\frac{111}{2}$.

Tetrahedron with Deltoid Dodecahedron, fig. 123, $\frac{111}{2}, \frac{11m}{2}$; fig. 124, $\frac{11m}{2}, \frac{111}{2}$; fig. 125, $\frac{11m}{2}, -\frac{111}{2}$.

Tetrahedron with Six-faced Tetrahedron, fig. 126, $\frac{1mn}{2}, \frac{111}{2}$; fig, 127, $\frac{1mn}{2}, -\frac{111}{2}$.

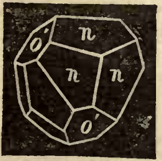

Fig. 121

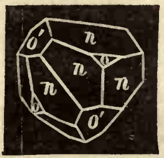

Fig. 122.

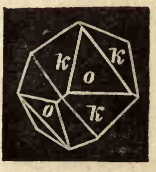

Fig. 123

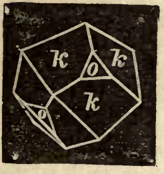

Fig. 124.

Fig. 125.

Fig. 126.

Fig. 127.

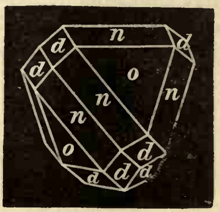

Fig. 128.

52. A complex form occurring in fahlerz is given in fig. 128, where $o = \frac{111}{2}$, $n = \frac{1mm}{2}$, $d = 11\infty$.

A still more complex form which occurs in the same mineral is given in fig. 129. The signs are as follows:—

$o = -\frac{111}{2}$

$a = 1\infty\infty$

$n^1 = -\frac{1mm}{2} = 122$

$n = +\frac{1mm}{2} = 122$

$e = 1m\infty = 13\infty$

$k = -\frac{11m}{2}\,; = \frac{11\frac{3}{2}}{2}$

$d = 11\infty$

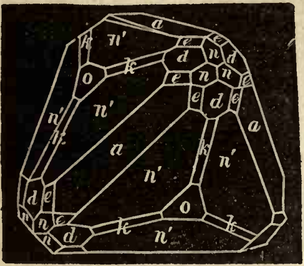

Fig. 129.

53. Platonic Bodies.—These are the only *regular* solids which can be formed, *i.e.*, the only bodies which are bounded by *equal*, *similar*, *regular*, and *rectilineal* figures. They are five in number, viz.:—

The *tetrahedron*, bounded by four equal equilateral triangles.
The *cube*, bounded by six equal squares.
The *octahedron*, bounded by eight equal equilateral triangles.
The *pentagonal dodecahedron*, bounded by twelve equal regular pentagons.
The *icosahedron*, bounded by twenty equal equilateral triangles.

The first three of these forms are common among natural crystals, but the two latter have not been observed. Figs. 49 and 87 sometimes afford a near approach to them, but the bounding planes are not *equilateral* pentagons and triangles, respectively.

54. The series of figures of cubical forms and combinations might be very much extended, but it will be found abundantly sufficient by every careful student. A few more remarkable combinations will be given when the minerals in which they occur come to be described.

CHAPTER VIII.

FORM (*Continued*)—THE TETRAGONAL OR PYRAMIDAL SYSTEM.

55. Axes.—In this system there are three axes as in the cubical, and they are also placed at right angles to each other, but they are not equal in length, one being longer or shorter than the other two. This is called the *principal* axis, the two that are equal are *lateral* axes.

56. Angular Elements.—The angle made by the principal axis with the *normals* (Art. 18) to the planes of one of the chief pyramids (usually the square pyramid of the so-called *second* order, figs. 133, 134), occurring in any natural substance crystallising in this system, is called the *angular element* of that substance.

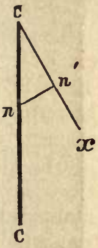

Fig. 130.

Thus, if *c c*, fig. 130, be the principal axis and *c x* a plane of the chief pyramid, then $n\ n^1$ will be a normal to that plane and the angle $n^1\ n\ c$ will be the *angular element.* With an angular element of 45° the planes of the chief pyramid of the *first* order in this system would coincide with those of the regular octahedron of the cubical system. This angle has not actually been met with in nature, but chalcopyrite has an angular element of 44° 31′, so that some of its forms are scarcely distinguishable from those belonging to the cubical system. The principal pyramids of the minerals anatase, nagyagite, and matlockite, are very acute, the angular elements being about 60°. Very obtuse pyramids are met with in cassiterite, rutile, scapolite, and zircon, while the chief pyramid in idocrase is so obtuse that its angular element is only 28° 9′.

With a few exceptions the perspective figures illustrating this chapter are those of crystals with medium angular elements.

57. HOLOHEDRAL FORMS—PYRAMIDS. The only complete holohedral forms in the pyramids $h\ k\ l$ in which all three signs are finite, *i.e.*, less than ∞. They are of three orders, as follows:—

1st. **The Tetragonal Pyramid,** of first order, figs. 131, 132. —Symbols, 111 *Mitchell*, 111 or $h\ h\ l$ *Miller*, P. *Naumann.* These are bounded by eight equal *isosceles* triangles. They are therefore octahedrons, but differ from the regular octahedrons, fig. 15, in which the planes are equilateral triangles. In fig. 131 the principal axis $l-l$ is longer than the lateral axes $h-h$, $k-k$. In fig. 132 it is shorter. The edges terminating at the principal axes are termed *polar*, those which only connect the lateral axes are *lateral.*

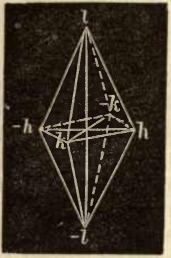

Fig. 131.

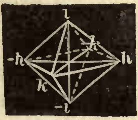

Fig. 132.

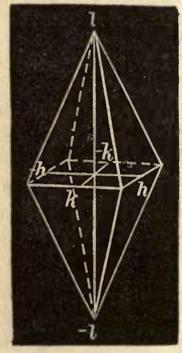

Fig. 133.

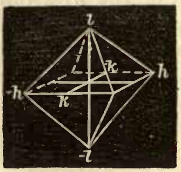

Fig. 134.

Fig. 135.

2nd. **The Tetragonal Pyramid,** of second order, figs. 133, 134. —Symbols, 1 ∞ 1 *Mitchell*, 101 or $h\ o\ l$ *Miller*, P∞ *Naumann.* These do not at all differ in appearance from the pyramids already described, but only in the situation of tho lateral axes, as shown in the figures. Fig. 135 is a plan or end view of these two orders of tetragonal pyramids, the completed lines showing the situation of the lateral planes in the pyramid of the first order, the dotted lines those of the second order.

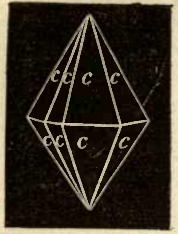

Fig. 136.

Fig. 137.

3rd. **The Ditetragonal Pyramids,** fig. 136.—Symbols, $1m1$ *Mitchell*, *h k l Miller*, *m* P *n Naumann*. These pyramids are bounded by sixteen equal scalene triangles. The origin of these pyramids will be understood from a consideration of fig. 137, which is a plan of the crystal showing the lateral axes $h-h$, $k-k$. It will be seen that each face would, if produced, cut the prolonged parameters at points x x beyond $h-h$, $k-k$. This distance $o\,x$, which is always greater than $o\,h$ or $o\,k$, is denoted by the symbol m, consequently the symbol of the form will be $1m1$. In the figure $o\,x =$ twice $o\,h$, consequently $m = 2$, and the particular symbol of the form will be 121. In these pyramids m may have any value greater than 1 and less than ∞, as indicated in fig. 138, which also shows the situation of the axes in tetragonal pyramids of the first and second orders. Here AAAA are faces of the pyramid of first order, symbol 111; BB, etc., are faces of pyramids of the second order, symbol 1∞1; CC etc., faces of the ditetragonal pyramid, with the symbol 12½1; *o o.* are faces of other ditetragonal pyramids, with the symbols 11½1, 121, 131, 141, respectively, as indicated by the dotted lines. From this figure it is evident that the number of possible ditetragonal pyramids is infinite, m having all possible values between 1 and ∞, the limits of the pyramids of first order and second order. In the case when the parameter m is 2½, as shown in the figure at CC etc., the angles at *d d* are nearly equal to the angles at *h* 1 or *k* 1, and the sixteen bounding planes of the form are *scalene,* but scarcely differ from *isosceles* triangles. In this case the form may be mistaken for a combination of the pyramids of the first and second order, with the symbol $111 + 1\infty 1$.

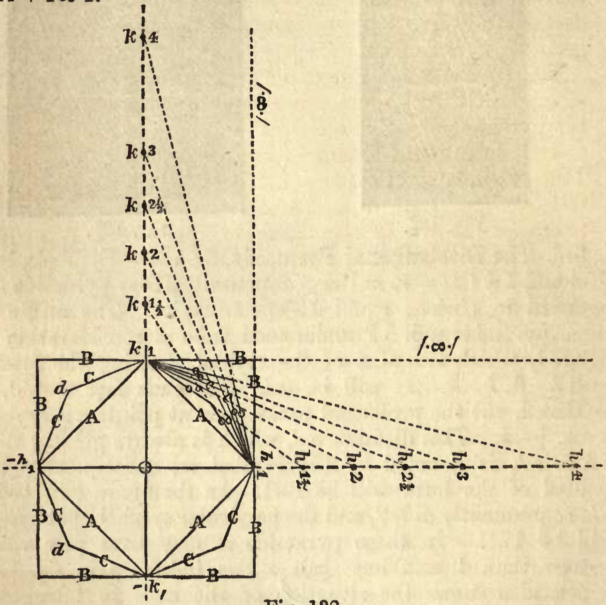

Fig. 138.

58. Derivative Pyramids.—From each of the pyramids described in Art. 57, others are derived by increasing or diminishing the principal axis, the lateral axes remaining unaltered, as shown in fig. 139, which represents a series of three pyramids of the first order, all relating to the same series of axes. The primary pyramid A is inclosed in another more acute, *a* 2, in which the principal axis is doubled. It also incloses a more obtuse pyramid, $a\,\frac{1}{2}$, in which the principal axis is reduced one-half. The symbol of A is therefore 111, that of *a* 2 is 112, that of $a\,\frac{1}{2}$, $11\frac{1}{2}$.

The *general* symbol, expressing the whole series, will therefore be 11*m* *Mitchell*, *h h l* *Miller*, *m* P *Naumann*. Similar pyramids may exist of the second order with the *general* symbol 1 ∞ *m* *Mitchell*, *h o l* *Miller*, *m* P ∞ *Naumann*, all being derived in a similar way. These are also derived ditetragonal pyramids with the general symbol 1*mn*.

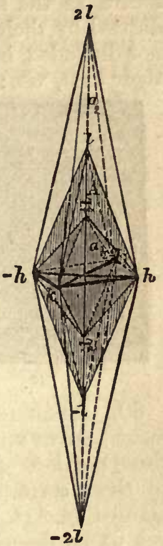

Fig. 139.

59. Holohedral Forms—Prisms. These also are of three orders corresponding with the pyramids already described:—

1st. **Tetragonal Prism**, of first order, fig. 140.—Symbols, 11∞, ∞ ∞ 1 *Mitchell*, 110, 001 *Miller*, ∞ P, 0 P *Naumann*. This prism is shown in the figure in relation to its corresponding pyramid, which is enclosed by it. It is also represented by the lines AAAA., in fig. 138.

2nd. **Tetragonal Prism**, of second order, fig. 141.—Symbols, 1∞ ∞, ∞ ∞1 *Mitchell*, 100, 001 *Miller*, ∞P∞, 0 P *Naumann*. This is shown in relation to its corresponding pyramid in fig. 141, and to the pyramid of first order in fig. 142. These prisms of first and second orders, like the corresponding pyramids, differ only in the situation of the lateral axes. In both, the principal axis joins the central points of the top and bottom planes called the *basal* planes or basal *pinacoids*. The positions of the lateral axes are clearly shown in the diagrams. BBBB, fig. 138, indicate the planes of the prism of second order.

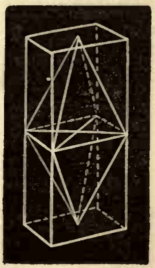
Fig. 140.

3rd. The **Ditetragonal Prism**, fig. 142*a*.—Symbols, 1*m*∞, ∞ ∞1 *Mitchell*, *h k o*, 001 *Miller*, ∞P *n*, 0 P *Naumann*. This prism, like the others, is shown in relation to its corresponding pyramid. When *m* equals 2½, the base of the prism scarcely differs from a regular octagon, when the form may be mistaken for a combination of the square prisms of the first and second order. Unlike the pyramids, which are complete in themselves, these prisms are *open* or *incomplete* forms, as the length of the principal axis is in no way indicated by their symbols. The planes at top and bottom are not included in the " form," but have a separate symbol of their own, viz.: ∞ ∞1 *Mitchell,* 001 *Miller,* or 0P *Naumann.*

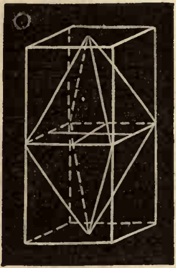
Fig. 141.

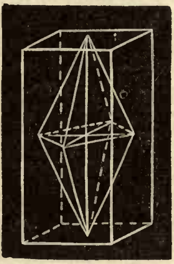
Fig. 142.

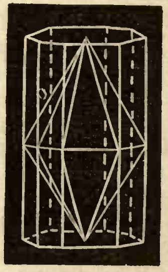
Fig. 142*a*.

60. Order and Significance of Symbols.—The student must bear in mind that in this and the following systems the three portions of each symbol, as 111 or 1∞ 1, refer not only to their corresponding parameters in regular order as explained in Art. 30, but they refer here, and in the systems yet to be described, to parameters which are not equal to each other as in the cubical system. Thus, the symbol 111 does not imply that the first, second, and third parameters are equal, but that they are respectively undivided or not multiplied. In 11$\frac{3}{4}$, for instance, the $\frac{3}{4}$ of the third parameter may be greater, absolutely, than the 1 of the first or second parameters: it simply implies that the face in question cuts the third parameter at three-fourths of *its own proper* length. This fact must ever be borne in mind.

CHAPTER IX.

FORM (*Continued*)—THE TETRAGONAL SYSTEM—HEMIHEDRAL AND TETARTOHEDRAL[*] FORMS.

61. From each of the forms just described, with the exception of the prisms of first and second orders, hemihedral forms are produced by the development of one-half the faces.

The hemihedral forms with *inclined* faces are "sphenoids"[†] (irregular tetrahedrons), trapezohedrons and scalenohedrons; those with parallel faces are four-faced pyramids, differing only in the situation of the axes from the holohedral pyramids of first and second orders.

62. Hemihedral Forms of Tetragonal Pyramids.

In the following figures, 143 to 226, faces parallel to the pyramids of the first order, $11m = hhl = m\mathrm{P}$, are lettered (*a*).

Faces parallel to the pyramids of the second order, $1\infty m = hol = \mathrm{P}\infty$, are lettered (*b*).

Faces parallel to the ditetragonal pyramids, $1mn = hkl = m\mathrm{P}n$, are lettered (*c*).

Prisms of first order, $11\infty = 110 = \infty\mathrm{P}$, are lettered (*m*).

Prisms of second order, $1\infty\infty = 100 = \infty\mathrm{P}\infty$, are lettered (*n*).

Ditetragonal prisms, $1m\infty = hko = \infty\mathrm{P}n$, are lettered (*q*).

The basal plane, $\infty\infty1 = 001 = 0\mathrm{P}$, is lettered (*o*).

(1.) Sphenoids derived from pyramids of first order, fig. 143. Symbols, $\frac{111}{2}$ or $\frac{11m}{2}$ *Mitchell*, $\frac{\mathrm{P}}{2}$ or $\frac{m\mathrm{P}}{2}$ *Naumann*, $\kappa 111$ or κhhl *Miller*. The mode by which this sphenoid is derived from the pyramid is shown in fig. 144, which represents the pyramid within the sphenoid. Fig. 145 shows its derivation from the corresponding square prism. Fig. 146 shows the derivation of the corresponding *negative* sphenoid $-\kappa hhl$.

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[*] τεταϱτος (*tetartos*), fourth, and ἕδϱα.

[†] ςφενος (*sphenos*), a wedge, and ειδος.

(2) Sphenoids derived from pyramids of second order, fig. 147, symbols $\frac{1\infty 1}{2}$ or $\frac{1\infty m}{2}$ *Mitchell*, $\frac{P\infty}{2}$ or $\frac{mP\infty}{2}$ *Naumann*, $\kappa\ h\ o\ l$ *Miller*. Fig. 148 shows the mode by which it is derived from the pyramid $1\infty\,m$, and fig. 149 its relation to the corresponding square prism $1\infty\,\infty$. Fig. 150 is the *negative* sphenoid $-\kappa\ h\ o\ l$.

63. Hemihedral Forms of the Ditetragonal Pyramid.—These are of several kinds according to the special law of development in question. In order to make these plain we will represent the eight upper planes of the ditetragonal pyramid, fig. 151,* the symbols $e_1\ e_2$ - - - - - e_8 and the eight lower planes by the symbols $e'_1\ e'_2$ - - - - - e'_8. The various hemihedral forms will then be as follows:—

(1.) The tetragonal scalenohedron, fig. 152. Symbols, $\frac{1mn}{2}$ *Mitchell*, $\frac{mPn}{2}$ *Naumann*, $\kappa\ h\ k\ l$ *Miller*. This is produced by the development of the planes $e_1\ e_2$, $e'_3\ e'_4$, $e_5\ e_6$,$e'_7\ e'_8$. This is the positive scalenohedron, by developing the remaining faces instead of those mentioned, the *negative* form $\kappa\ \bar{h}\ \bar{k}\ \bar{l}$ will result.

(2.) A very similar form, differing mainly in the situation of the axes, is produced if the planes $e_8\ e_1$, $e'_2\ e'_3$, $e_4\ e_5$, $e'_6\ e'_7$ are developed. *Mitchell* and *Naumann's* symbols are the same as for the preceding figure, but *Miller* distinguishes it by the sign $\lambda\ h\ k\ l$. The corresponding negative form is $\lambda\ k\ h\ l$.

(3.) The pyramidal trapezohedron, fig. 153, is produced by developing the faces $e_1\ e_3\ e_5\ e_7$, $e'_2\ e'_4\ e'_6\ e'_8$. No special symbols are given by *Mitchell* or *Naumann*, but *Miller's* is $\alpha\ h\ k\ l$ for the positive form and $\alpha\ k\ h\ l$ for the negative.

The three forms just described are hemihedral with inclined faces; a hemihedral form with parallel faces remains to be described.

(4.) The hemihedral double four-faced pyramid, which differs from the holohedral pyramids of first and second order only in the situation of the axes, is produced by developing the faces $e_1\ e_3\ e_5\ e_7$, $e'_1\ e'_3\ e'_5\ e'_7$. *Mitchell* and *Naumann* have no special symbols for these pyramids, but *Miller's* are $\pi\ h\ k\ l$ for the positive, and $\pi\ k\ h\ l$ for the negative.

64. Tetartohedral Forms of the Ditetragonal Pyramid.—The hemihedral double four-faced pyramids just described

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* Only a few of the letters are put in, for the sake of clearness, and for the same reason the principal axis is omitted.

Fig. 143.

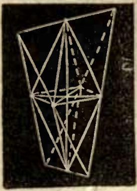


Fig. 144.

Fig. 145.

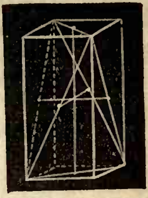


Fig. 146.

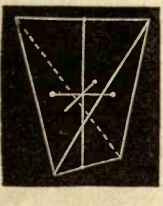


Fig. 147.

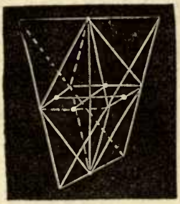


Fig. 148.

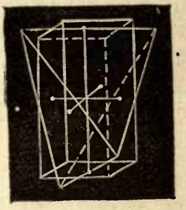


Fig. 149.

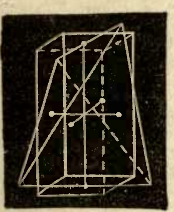


Fig. 150.

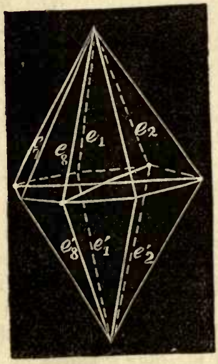


Fig. 151.

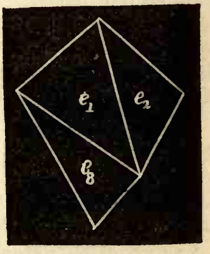


Fig. 152.

Fig. 153.

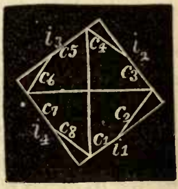


Fig. 154.

themselves admit of a hemihedral development, so producing sphenoids of only one-fourth the original number of faces. It is however doubtful whether these sphenoids have been observed in nature. They would differ from the sphenoids, figs. 143, 147, only in the situation of the axes.

65. Hemihedral Forms of the Ditetragonal Prism.—Symbol, $\frac{1m\infty}{2}$. These will be square prisms differing from those of the first and second orders only in the situation of the axes. Fig. 135 shows the situation of the lateral axes in the prism 11∞ and $1\infty\infty$; fig. 154 their situation in the ditetragonal prism $1m\infty$ $c_1 c_2$ - - - - - c_8, and the positive hemihedral square prism $\frac{1m\infty}{2}$ $i_1 i_2 i_3 i_4$ produced by developing the faces $c_1 c_3 c_5 c_7$. The negative prism $-\frac{1m\infty}{2}$ is produced by developing the remaining faces.

66. Sphere of Projection of the Tetragonal System.—This is shown in fig. 155, the construction of which is evident. The centre (o) is the pole of the basal planes $\infty\infty 1$. The poles of the faces of the pyramids of first order $11m$, will fall on the lines ox_1, ox_2, ox_3, ox_4, more or less distant from o according to the greater or less angular element of the crystal in question, the "latitude" being equal to the "angular element." The poles of the planes of second order pyramids, $1\infty m$, will fall on the lines $o\,h$, $o-h$, $o\,k$, $o-k$ in the same manner; those of the ditetragonal pyramids, $1nm$, will fall in the triangles. The poles of the prisms 11∞ will be at $x_1\, x_2\, x_3\, x_4$, those of the prisms $1\infty\infty$ at h, $-h$, k, $-k$; those of the ditetragonal prisms $1n\infty$ on the line h, x_1, k, etc., and between the points marked.

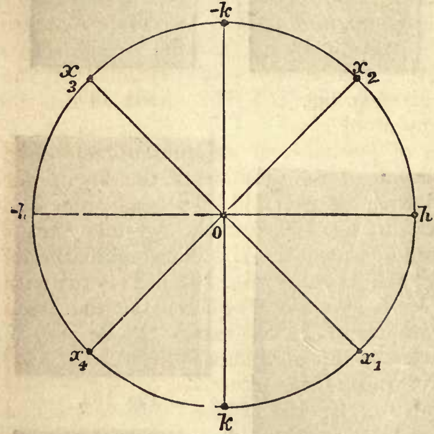


Fig. 155.

CHAPTER X.

FORM (*Continued*)—HOLOHEDRAL COMBINATIONS OF THE TETRAGONAL SYSTEM.

67. Combinations of Pyramids with each other.—(1.) Combinations of pyramids of the same order (*derived pyramids*). These will be understood by a reference to fig. 156, which represents a combination of the three pyramids like those shown in fig. 139. The faces of the primary pyramid are in both figures indicated by the letter A, those parallel to the *acute* pyramid by a_2; parallel to the *obtuse* pyramid by $a\frac{1}{2}$. Other combinations of pyramids of the same order are also given in figs. 157, 158, in which A = the pyramid 111, *a* the pyramid 11*m*.

(2.) Combinations of pyramids of different orders. Fig. 159 shows a combination of the pyramid of the first order *a* (11*m*), with the tetragonal pyramid of second order and different slope 1∞*m*. In fig. 160, *a* is the pyramid 11*m*, *c* the ditetragonal pyramid 1*mm*; fig. 161 is a combination of the pyramids 1*nm* (*c*) and 11*m* (*a*); fig. 162 is 11*m* (*a*) with 1∞*m* (*b*), in which *b* is a pyramid of different altitude to *a* (*i.e.*, *m* has different values in the two cases).

68 Pyramids with the Basal Plane.—Figs. 163, 164, show combinations of incomplete pyramids, with the basal pinacoid *o*. The symbol of fig. 163 is 11*m* (*a*), ∞∞1 (*o*), of fig. 164, 1*nm* (*c*), ∞∞1 (*o*).

69. Combinations of Pyramids with Prisms.—(1.) Combinations of pyramids and prisms of the same order. Examples are given in figs. 165 and 166, where *a* is the pyramid and *m* the prism. The figures represent combinations of forms of the first order, but with a slight change of position would equally represent those of the second order.

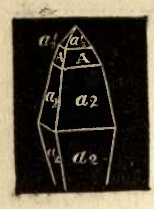


Fig. 156.

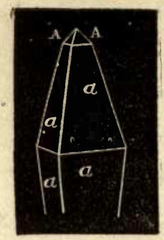


Fig. 157.

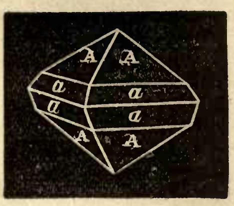


Fig. 158.

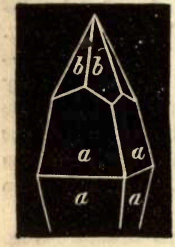


Fig. 159.

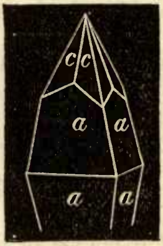


Fig. 160.

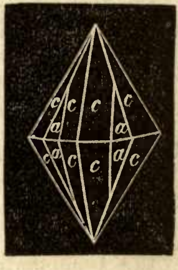


Fig. 161.

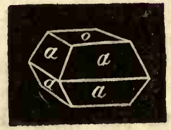


Fig. 163.

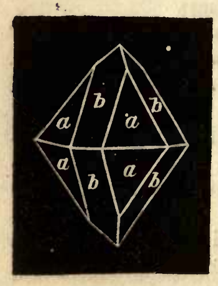


Fig. 162.

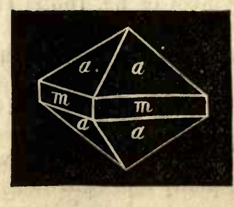


Fig. 165.

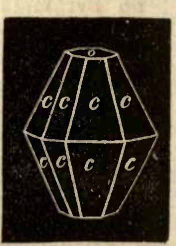


Fig. 164.

(2.) Combinations of ditetragonal pyramids and prisms are given in figs. 167, 168, where c is the pyramid and q the prism.

(3.) Combinations of prisms of different orders. Fig. 169 is the prism of first order 11∞ (m) combined with the prism of the second order $1\infty\infty$ (n); fig. 170 is prism of first order 11∞ (m), with ditetragonal prism $1n\infty$ (q). Each shows the basal plane $\infty\infty1$ (o).

Figs. 171, 172 represent the pyramid of first order (a) with prism of second order (n), the symbol being 111, $1\infty\infty$.

Fig. 173 is the pyramid of first order (a), with ditetragonal prism (q), having the symbol 111, $1n\infty$.

Fig. 174 is a ditetragonal pyramid (c) and ditetragonal prism (q). The symbol is $1nm$, $1n'\infty$, as the n has different values for pyramid and prism, it is in the latter distinguished by an accent.

Fig. 175 is the ditetragonal pyramid (c) and square prism of first order (m), with the symbol $1nm$, 11∞.

Fig. 176 is the pyramid of first order (a), of second order (b), and prism of first order (m), the symbol being 111, $1\infty1$, 11∞.

Fig. 177 shows the similar planes, except that b is $1\infty m$.

Fig. 178 shows the pyramid of first order (a), the ditetragonal pyramid (c), and the prism of second order (n), with the sign 111, $1nm$, $1\infty\infty$.

Fig. 179 is a more complex form, showing pyramid of first order (a), of second order (b), prism of first order (m), of second order (n), and the ditetragonal prism (q), with the basal plane (o). The symbol will be 111, $1\infty1$, 11∞, $1\infty\infty$, $1n\infty$, $\infty\infty1$.

Fig. 180 is still more complex, containing pyramid of first order (a), two pyramids of second order (b) and (b'), ditetragonal pyramid (c), square prism of first order (m), and second order (n), with ditetragonal prism (q), and basal plane (o). The complete symbol is 111, $1\infty1$, $1\infty m$, $1nm$, 11∞, $1\infty\infty$, $1n\infty$, $\infty\infty1$.

Fig. 181 shows pyramid of first order (a), two pyramids of second order (b) and (b'), ditetragonal pyramid (c), prism of first order (m) of second order (n), ditetragonal prism q. Symbol 111, $1\infty1$, $1\infty m$, $1nm$, 11∞, $1\infty\infty$, $1n\infty$.

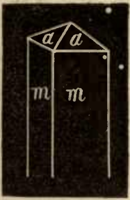


Fig. 166.

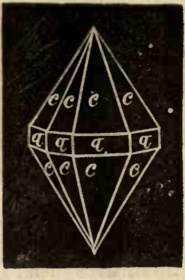
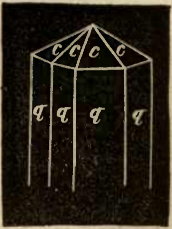


Fig. 167.



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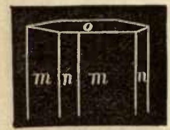
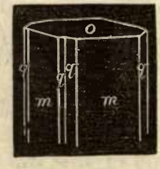


Fig. 169.



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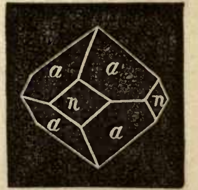

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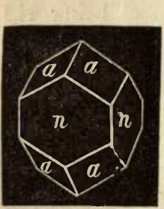

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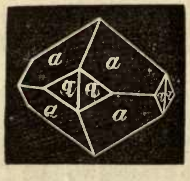

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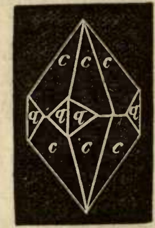

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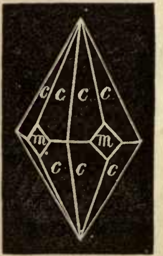

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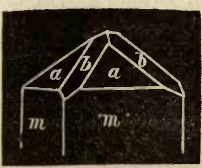

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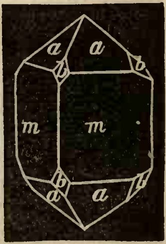

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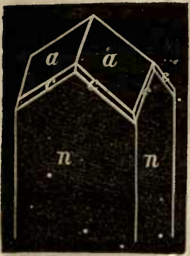

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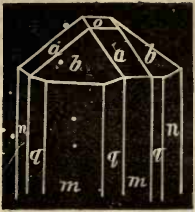
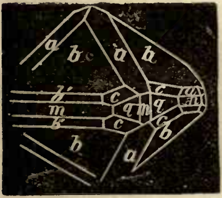


Fig. 179.

Fig. 180.



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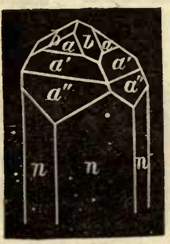

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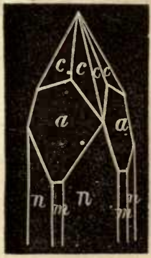

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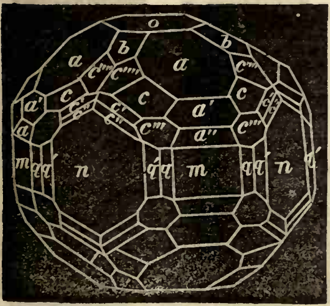


Fig. 184.

Fig. 185.

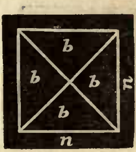
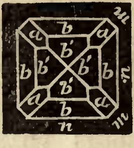


Fig. 186.

Fig. 187.

Fig. 188.

Fig. 189.



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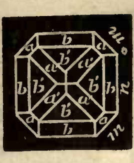
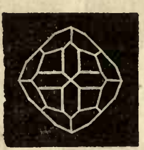


Fig. 191.

Fig. 192.

Fig. 193.



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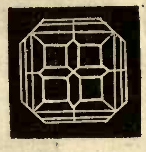

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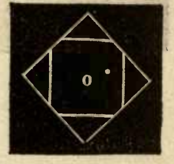

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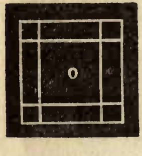

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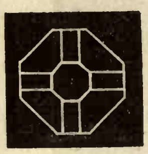
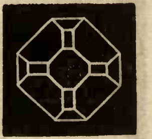


Fig. 198.

Fig. 199.



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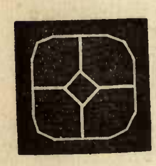


Fig. 201.

Fig. 202.

Fig. 203.

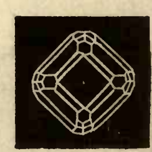


Fig. 204.

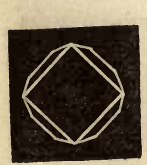


Fig. 205.

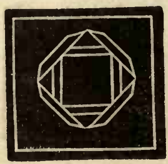


Fig. 206.

Fig. 207.

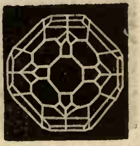


Fig. 208.

Fig. 182 shows three pyramids of first order (a) (a') (a''), pyramid of second order (b), prism of second order n, the symbol is 111, $11m$, $11m'$, $1\infty m$, $1\infty 1$.

Fig. 183 shows pyramid of first order (a), ditetragonal pyramid (c), prism of first order (m), of second order (n), with the symbol 111, $1nm$, 11∞, $1\infty\infty$.

Fig. 184 is a very complex crystal of idocrase, described by Mohr, having the following faces:

$a = 111$
$a' = 112$
$a'' = 114$
$b = 1\infty 1$
$c = 122$
$c' = 133$
$c'' = 144$
$c''' = 124$
$c'''' = 13\frac{3}{2}$
$m = 11\infty$
$n = 1\infty\infty$
$q = 12\infty$
$q' = 13\infty$
$o = \infty\infty 1$

70. Vertical Projection.—A very convenient mode of representing the planes occurring in minerals belonging to this system is the vertical projection often adopted by Professor Miller—a projection by lines parallel to the principal axis on a plane perpendicular to that axis. A series of holohedral figures drawn in this manner is given from figs. 185 to fig. 208.

It will be observed that this mode of representing crystals does not indicate the relative size or development of the planes of *prisms.* The existence of planes of the prisms can indeed only be indicated at all by the signs placed around the figure, as in fig. 186; where, if the sign n did not appear we should conclude that the crystal represented was a pyramid only, without the prismatic planes.

In figs. 185 to 192 similar planes are lettered, the rest are left as exercises for the student.

Up to fig. 195 the basal plane $\infty\infty 1$ (o) does not appear, after that all the figures to 208 show that plane.

CHAPTER XI.

FORM (*Continued*)—HEMIHEDRAL COMBINATIONS OF THE TETRAGONAL SYSTEM.

71. Combinations of Hemihedral Forms with each other.

(1.) The positive sphenoid $\frac{111}{2}$ (*a*) with the negative sphenoid $-\frac{111}{2}$ (*a'*), fig. 209. The student will note how much this figure resembles the combination, fig. 117, in the cubical system. Where the "angular element" of the tetragonal crystal in question approaches 45°, as in chalcopyrite; it is indeed impossible to distinguish the two forms without careful measurement. Fig. 210 is the same combination, but here the negative sphenoid is the most developed.

(2.) The positive sphenoid $\frac{111}{2}$ (*a*), negative sphenoid $-\frac{111}{2}$ (*a'*), and scalenohedron $\frac{115}{2}$ (*e*), fig. 211.

72. Combinations of Hemihedral with Holohedral Forms.

(1.) Positive sphenoid $\frac{111}{2}$ (*a*) with the prism of first order 11∞ (*m*). This is less like fig. 209 than it appears here.

(2.) Positive sphenoid $\frac{111}{2}$ (*a*) and prism of second order $1\infty\infty$ (*n*), fig. 213.

(3.) Positive sphenoid $\frac{11m}{2}$ (*a'*) with double four-faced pyramid $1\infty 1$ (*b*) fig. 214.

(4.) Pyramid of second order $1\infty 1$ (*b*) and negative sphenoid $-\frac{11m}{2}$ (*a'*), fig. 215.

(5.) Pyramid of second order $1\infty 1$ (*b*) and scalenohedron $\frac{1nm}{2}$ (*e*), fig. 216.

(6.) Positive sphenoid $\frac{111}{2}$ (*a*), negative sphenoid $-\frac{111}{2}$ (*a'*), scalenohedron $\frac{1mn}{2}$ (*e*), and prism of first order 11∞ (*m*) fig. 217.

(7.) Positive sphenoid $\frac{111}{2}$ (*a*), negative sphenoid $-\frac{111}{2}$ (*a'*), basal plane $\infty\infty 1$ (*o*), scalenohedrons $\frac{1mn}{2}$ (*e*) and $\frac{1'm'n}{2}$ (*e'*), fig. 218.

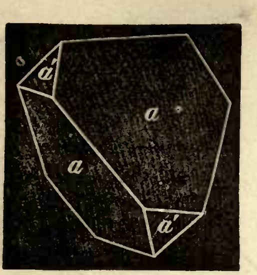


Fig. 209.

Fig. 210.

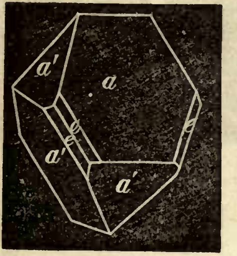


Fig. 211.

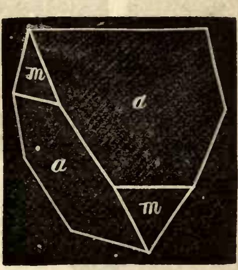


Fig. 212.

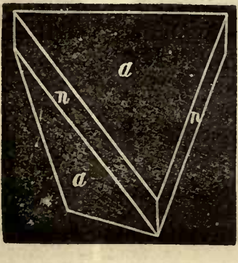


Fig. 213.

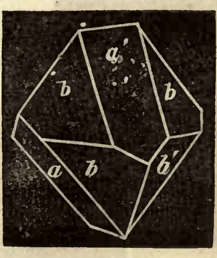


Fig. 214.

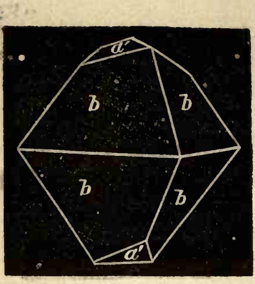


Fig. 215.

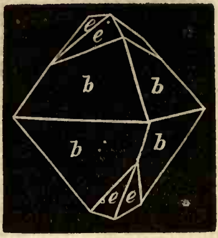


Fig. 216.

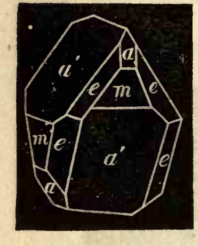


Fig. 217.

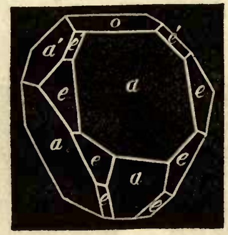


Fig. 218.

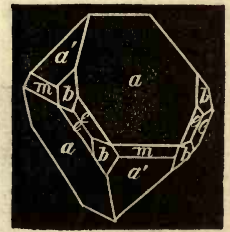


Fig. 219.

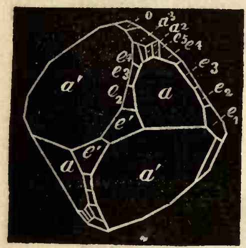


Fig. 220.

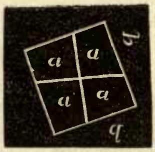


Fig. 221.

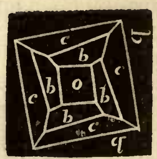


Fig. 222.

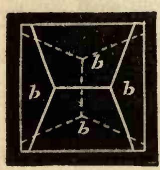


Fig. 223.

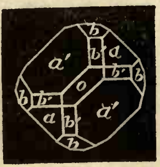


Fig. 224.

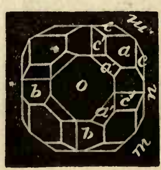


Fig. 225.

Fig. 226.

(8.) Positive sphenoid $\frac{111}{2}$ (a), negative sphenoid $-\frac{111}{2}$ (a'), scalenohedron $\frac{1mn}{2}$ (e), derived pyramid of second order $1\infty 2$ (b), and prism of first order 11∞ (m), fig. 219.

(9.) Positive sphenoid $\frac{111}{2}$ (a), negative sphenoid $-\frac{111}{2}$ (a'), positive sphenoid $\frac{11m}{2}$ (a^2), positive sphenoid $\frac{1'1'm'}{2}$ (a^3), basal plane $\infty\infty 1$ (o), and five scalenohedrons $\frac{1nm}{2}$ ($e^1 e^2 e^3 e^4 e^5$), fig. 220.

73. A few vertical projections of hemihedral forms are given in figs. 221 to 226.

Fig. 221 shows the planes of the pyramid of first order (a), those of the hemihedral form of the ditetragonal prism $\frac{1m\infty}{2}$ are indicated by the sign (q).

Fig. 222 is the hemihedral form of the ditetragonal prism $\frac{1m\infty}{2}$ (q), the hemidedral double four-faced pyramid $\frac{1mn}{2} = a\,h\,k\,l$ (e), the pyramid of second order $1\infty m$ (b), and the basal plane $\infty\infty 1$ (o).

Fig. 223 is the sphenoid derived from the prism of second order $\frac{1\infty n}{2} = \kappa\,h\,o\,l$ (b).

Fig. 224 shows the positive sphenoid derived from the pyramid of first order $\frac{111}{2}$ (a), the negative sphenoid (a'), pyramid of second order (b) and (b'), basal plane (o), the prism of second order $1\infty\infty$ (n), and the ditetragonal prism (q).

Fig. 225 shows two pyramids of first order a and a', ditetragonal pyramid c, sphenoid derived from a ditetragonal pyramid c', and the pyramid of second order (b).

Fig. 226 is a pyramid of second order (b), and three sphenoids derived from ditetragonal pyramids $c\ c\ c$.

CHAPTER XII.

FORM (*Continued*)—THE RHOMBIC OR PRISMATIC SYSTEM.

74. Axes and Elements.—In this system there are three axes situated at right angles to each other. Two of these are known as *lateral*, the third is *principal*. All three are of different lengths. The greater lateral or "macrodiagonal" axis may be generally indicated by the sign $\pm h$, the lesser lateral by the sign $\pm k$, the principal by $\pm l$. In giving the symbols for the various forms and faces this order will always be observed. A plan of the two lateral axes is given in fig. 227. The vertical axis is at right angles to these. The system is known as *rhombic*, because its most perfect form is a double pyramid on a rhombic base; as *prismatic*, because of the great number of prisms which occur in it.

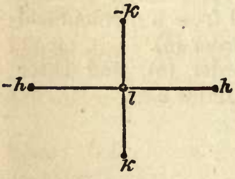


Fig. 227.

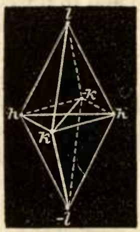


Fig. 228.

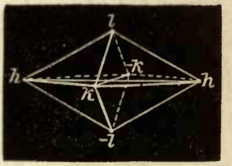


Fig. 229.

75. Holohedral Forms.—The only complete holohedral form is the rhombic pyramid *hkl*, in which *h*, *k*, *l*, are all finite. This is bounded by eight triangular planes, each cutting the three axes at some point less than ∞. Rhombic pyramids with the sign *hkl* are illustrated in figs. 228 and 229. From this complete form a series of partial forms result, when either *h*, *k*, or *l* becomes infinite. All of these forms are incomplete, *i.e.*, they must be combined with other forms to produce complete crystals. These partial forms, six in number, are produced as follows:—

1. When h becomes infinite the "macrodome" ∞kl or $\infty 11$.
2. When k becomes infinite the "brachydome" $h\infty l$ or $1\infty 1$.
3. When l becomes infinite the "rhombic prism" $hk\infty$ or 11∞.
4. When h and k become infinite the "basal pinacoid" $\infty\infty l$ or $\infty\infty 1$.
5. When h and l become infinite the "macropinacoid" $\infty k\infty$ or $\infty 1\infty$.
6. When k and l become infinite the "brachypinacoid" $h\infty\infty$ or $1\infty\infty$.

The forms 11∞, $h1\infty$, and $1k\infty$, when combined with $\infty\infty 1$, compose a series of complete rhombic prisms, which may be called prisms of the 1st, 2nd, and 3rd orders.

The forms ∞kl and $1\infty\infty$ together compose a rhombic prism of 4th order.

The forms $h\infty l$ and $\infty 1\infty$ together compose a rhombic prism of 5th order.

The forms $\infty\infty 1$, $\infty 1\infty$, and $1\infty\infty$ together compose a rectangular prism.

76. Right Rhombic Pyramids.—These are bounded by eight equal scalene triangles. The general aspect varies much according to the relative length of the axes. Fig. 228 represents a pyramid in which the vertical axis is much greater than the two laterals; fig. 229, one in which it is much shorter. The symbols of these pyramids will be 111 *Mitchell* and *Miller*, P *Naumann.**

77. Derived Rhombic Pyramids.—Of these there are five varieties as follows:—

a. With the parameter l, multiplied or divided, consequently the sign is $11m$ *Mitchell,* $11l$ *Miller,* mP *Naumann.*

b. With the parameter k, multiplied or divided, the sign is $1m1$ *Mitchell,* $1k1$ *Miller,* $\breve{\bar{\mathrm{P}}}n$ *Naumann.*

c. With the parameter h, multiplied or divided, the sign is $m11$ *Mitchell,* $h11$ *Miller,* $\bar{\mathrm{P}}n$ *Naumann.*

---

* It must be remembered that as in the pyramidal system so here the sign 111 does not imply *equality* of the axes or parameters, since each has its own proper length; but simply that they are neither multiplied nor divided in the case in question.

d. With the parameters *k* and *l*, multiplied or divided—sign 1*nm* *Mitchell*, 1*kl* *Miller*, $m\breve{P}n$ *Naumann.*

e. With the parameters *h* and *l* multiplied or divided—sign *m*1*n* *Mitchell*, *h*1*l* *Miller*, $m\bar{P}n$ *Naumann.*

Of these the second and fourth are called "brachypyramids," the third and fifth "macropyramids."

78. Right Rhombic Prisms.—These are incomplete forms combined with the basal pinacoid $\infty\infty 1$. They are of five orders as follows:—The plane $\infty\infty 1$ *Mitchell*, 001 *Miller*, 0P *Naumann*, occurs in all—

1st Order—sign 11∞ *Mitchell*, 110 *Miller*, ∞P *Naumann.*

2nd Order—sign $m1\infty$ *Mitchell*, *h*10 *Miller*, $\infty\bar{P}$ *Naumann.* These are called "macroprisms."

3rd Order—sign $1m\infty$ *Mitchell*, 1*k*0 *Miller*, $\infty\breve{P}$ *Naumann.* These are called "brachyprisms."

Fig. 230.

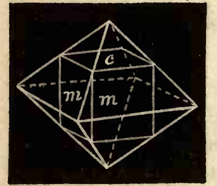


Fig. 232.

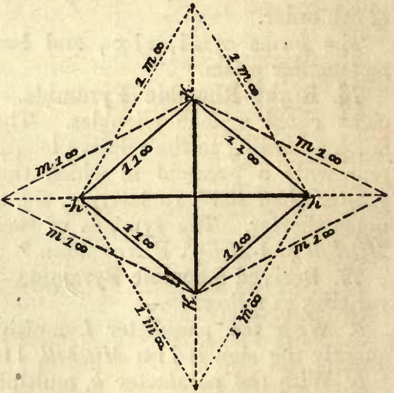


Fig. 231.

The relation of the prism 11∞ to the axes is shown in fig. 230, where *mm* are the faces 11∞. The situation of the prism within the pyramid 111 is given in fig. 232. Fig. 231 shows the relations of the three forms 11∞, $m1\infty$, and $1m\infty$, to the lateral axes.

4th Order, the "macrodome"—sign ∞mm *Mitchell*, $0kl$ *Miller*, $\bar{P}\infty$ *Naumann*, combined with the "brachypinacoid," $1\infty\infty$ *Mitchell*, 100 *Miller*, $\infty\breve{P}\infty$ *Naumann*.

The position of this form within the pyramid 111 is given in figs. 233 and 234, where *w* represents the faces $\infty 11$.

5th Order, the "brachydome"—sign $m\infty m$ *Mitchell*, $h0l$ *Miller*, $\breve{P}\infty$ *Naumann*, combined with the "macropinacoid" $\infty 1\infty$ *Mitchell*, 010 *Miller*, $\infty\bar{P}\infty$ *Naumann*.

Its position within the pyramid 111 is shown in fig. 235, where *v* represents the face $1\infty 1$.

79. Right Rectangular Pyramids.—These are sometimes produced by a combination of the planes of the macrodome $\infty 11$ (*w*) with the brachydome $1\infty 1$(*v*) as in fig. 236. The situation of the axes is well shown in the figure.

80. Right Rectangular Prisms.—This is composed of the three forms $\infty\bar{P}\infty$, $\infty\breve{P}\infty$, OP *Naumann*, these three forms being the macropinacoid, the brachypinacoid, and the basal-pinacoid respectively. This form is illustrated in figs. 237, 238.

81. Combination of Pyramids with Pyramids.—Pyramids 111 (*e*) $11m$ (*e*′), fig. 239.

82. Pyramids with Pinacoids and Prisms.—Pyramid 111 (*e*) and basal pinacoid $\infty\infty 1$ (*c*), fig. 240.

Pyramid 111 (*e*) and macropinacoid $\infty 1\infty$ (*b*), fig. 241.

Pyramid 111 (*e*) and brachypinacoid $1\infty 1$ (*a*), fig. 242.

Pyramid (*e*) with brachypinacoids and macropinacoids (*a*) and (*b*), fig. 243.

The same with basal pinacoid $\infty\infty 1$ (*c*), fig. 244.

Pyramid 111 (*e*) with prism 11∞ (*m*), fig. 245.

83. Pyramids with Brachydomes and Macrodomes.—Pyramid 111 (*e*) and the brachydome $1\infty 1$ (*v*), fig. 246.

Pyramid $1nm$ (*e*), brachydome $\infty 1m$ (*d*), macrodome $\infty 1m'$ (*s*′), and brachydome $\infty m1$ (*s*″), fig. 247.

84. Pyramids with Domes and Prisms.—Pyramid 111 (*e*), macrodome $\infty 11$ (*w*), and brachyprism 12∞ (*p*), fig. 248.

Pyramid 111 (*e*), brachyprism 12∞ (*p*), prism 11∞ (*m*), brachydome $1\infty 1$ (*v*), fig. 249.

Pyramid $11m$ (*e*′), brachydome $1\infty m$ (*v*), brachyprism $1n\infty$ (*p*′), and macroprism $n1\infty$ (*n*), fig. 250.

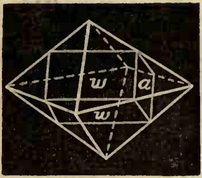


Fig. 233.

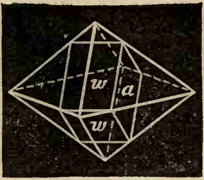


Fig. 234.

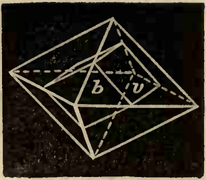


Fig. 235.

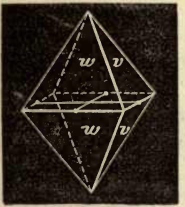


Fig. 236.

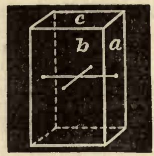


Fig. 237.

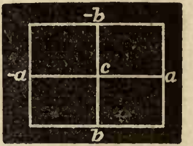


Fig. 238.

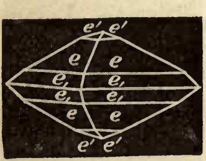


Fig. 239.

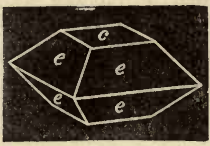


Fig. 240.

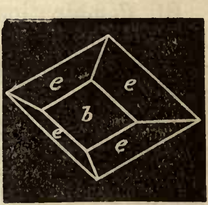


Fig. 241.

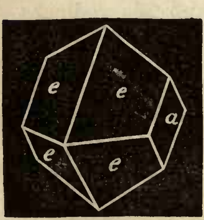


Fig. 242.

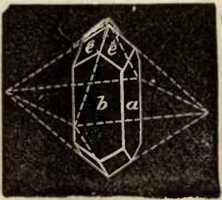


Fig. 243.

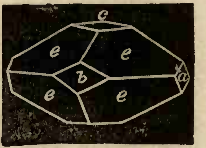


Fig. 244.

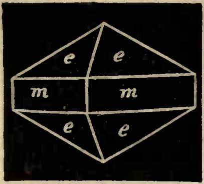


Fig. 245.

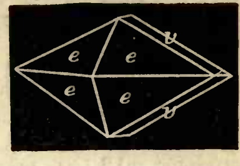


Fig. 246.

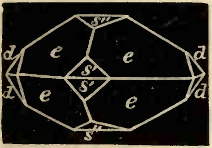


Fig. 247.

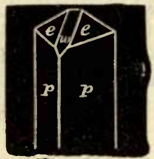


Fig. 248.

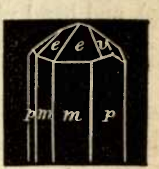
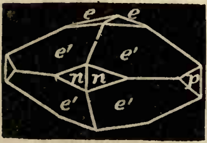


Fig. 249.



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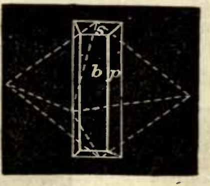
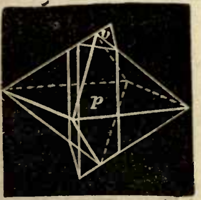


Fig 251.

Fig. 252.



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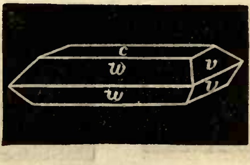


Fig. 254.

85. Domes, Prisms, and Pinacoids.—Macrodome $\infty 1\frac{1}{2}$ (*s*), brachyprism 12∞ (*p*), and macropinacoid $\infty 1 \infty$ (*b*), fig. 251.

Brachydome $1\infty m$ (*v*), brachypinacoid $1\infty\infty$ (*a*), and rhombic prism 11∞ (*m*), fig. 252.

Brachydome $1\infty m$ (*v*), and brachyprism 12∞ (*p*), fig. 253.

Macrodome $\infty 12$ (*s*), brachydome $1\infty 1$ (*v*), and basal pinacoid $\infty\infty 1$ (*c*), figs. 254, 255.

Macrodome $\infty 12$ (*w*), prism 11∞ (*m*), and basal pinacoid $\infty\infty 1$ (*c*), fig. 256.

Prism 11∞ (*m*), macroprism $n1\infty$ (*n*), brachydome $1\infty m$ (*v*), and basal pinacoid $\infty\infty 1$ (*c*), fig. 257.

Macroprism $n1\infty$ (*n*), brachypinacoid $1\infty\infty$ (*a*), pyramid 111 (*e*), and basal pinacoid $\infty\infty 1$ (*c*), fig. 258.

A complex crystal of barytes, described by Dana, from Cheshire, Connecticut, is illustrated in fig. 259. It exhibits the following forms :—

e	=	Pyramid	111	v'	=	Brachydome	$1\infty\frac{1}{2}$
e'	=	,,	$11\frac{1}{3}$	b	=	Macropinacoid	$\infty 1\infty$
e''	=	,,	$11\frac{1}{5}$	w_1	=	Macrodome	$\infty 12$
e'''	=	,,	$11\frac{1}{8}$	w	=	,,	$\infty 11$
m	=	Prism	11∞	w'	=	,,	$\infty 1\frac{1}{2}$
c	=	Basal pinacoid	$\infty\infty 1$	w''	=	,,	$\infty 1\frac{1}{4}$
a	=	Brachypinacoid	$1\infty\infty$	w'''	=	,,	$\infty 1\frac{1}{8}$
v	=	Brachydome	$1\infty 1$	n'	=	Macroprism	21∞

The complete crystal contains no fewer than 80 planes.

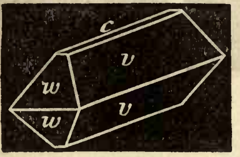


Fig. 255.

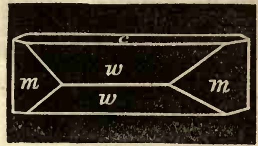


Fig. 256.

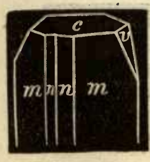


Fig. 257.

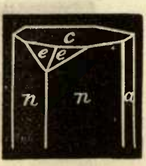


Fig. 258.

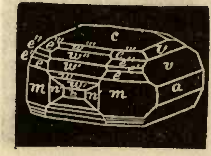


Fig. 259.

86. Vertical Projections.—A large series of rhombic crystals projected on a plane parallel to the basal plane $\infty\infty 1$ by lines parallel to the principal axis is given in figs. 260 to 349; the student will have little difficulty in assigning their proper names to the various planes.

Fig. 260 is the pyramid 111 or 11*m*, 261 to 264 are various combinations of pyramids and prisms, and 265 is the pyramid with the basal pinacoid.


Fig. 260.


Fig. 261.


Fig. 262.


Fig. 263.


Fig. 264.

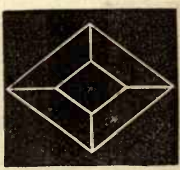


Fig. 265.

Figs. 266 to 271 are combinations of various prisms with the basal pinacoid.

Figs. 272 to 275 are various macrodomes; 276 is the macrodome with the basal pinacoid.

Figs. 277 to 282 are various brachydomes; 283 and 284 are brachydomes with the basal pinacoid.

Fig. 285 is that particular combination of the brachydome and macrodome which forms a double pyramid with rectangular base.

Fig. 286 is the macrodome and brachydome, the former predominating.

Fig. 287 is the same combination with the brachydome predominating.

Fig. 288 is another combination of domes, and figs. 289 and 290 show various brachydomes and macrodomes with the basal pinacoid.

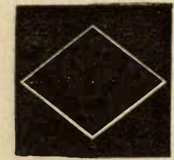


Fig. 266.

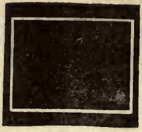


Fig. 267.

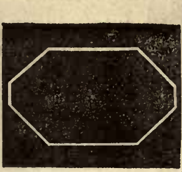


Fig. 268.


Fig. 269

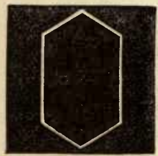


Fig. 270.


Fig. 271.

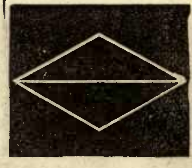


Fig. 272.


Fig. 273.

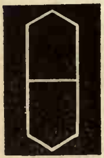


Fig. 274.

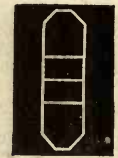


Fig. 275.


Fig. 276.

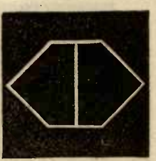


Fig. 277.


Fig. 278.

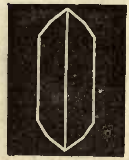


Fig. 279.

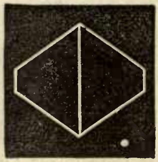


Fig. 280.

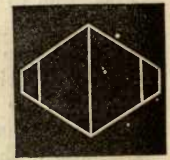
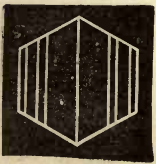


Fig. 281.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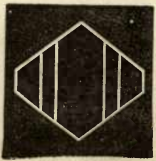


Fig. 283.

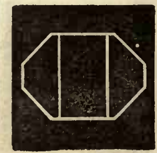
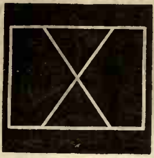


Fig. 284.


Fig. 285.

Fig. 286.



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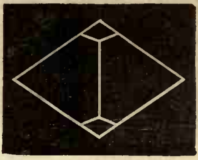
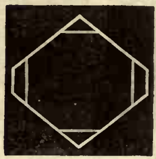


Fig. 288.

Fig. 289.



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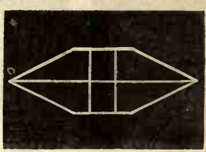


Fig. 291.

Fig. 292.

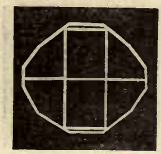


Fig. 293.

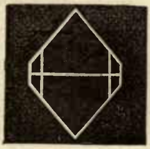


Fig. 294.

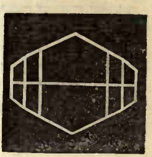


Fig. 295.

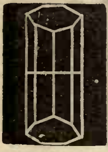
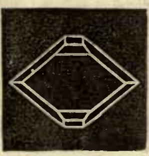


Fig. 296.



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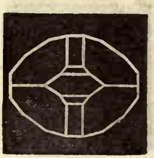


Fig. 298.

Fig. 299.

Fig. 300.

Fig. 301.

Fig. 302.

Fig. 303.

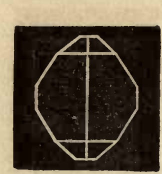


Fig. 304.

Fig. 305.

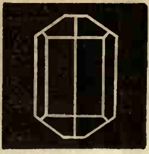
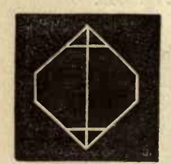


Fig. 306.

Fig. 307.



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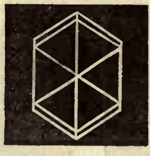


Fig. 309.

Fig. 310.

Fig. 311.

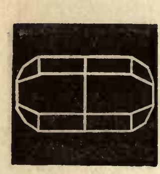


Fig. 312.

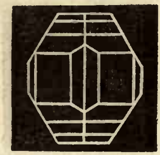


Fig. 313.

Fig. 314.

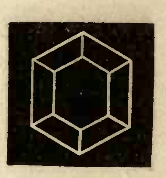


Fig. 315.

Fig. 316.

Fig. 317

Fig. 318.

Fig. 319.

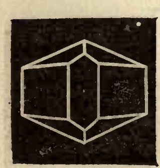


Fig. 320.

Fig. 321.

Fig. 322.

Fig. 323.


Fig. 324.


Fig. 325.


Fig. 326.

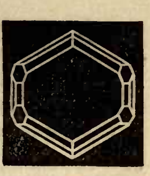


Fig. 327


Fig. 328.


Fig. 329.


Fig. 330.

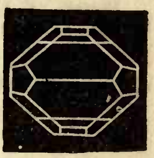


Fig. 331.


Fig. 332.

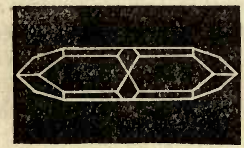


Fig. 333.

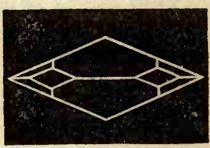


Fig. 334.

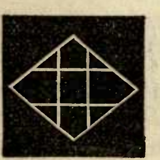


Fig. 335.


Fig. 336.


Fig. 337.


Fig. 338.


Fig. 339.


Fig. 340.

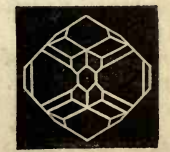


Fig. 341.

Figs. 291 to 296 are combinations of various pyramids and macrodomes.

Figs. 297 and 298, the same, with the addition of the basal pinacoid.

Figs. 299 to 314 are pyramids and brachydomes, 315 to 328 the same, with the basal pinacoid.

Figs. 329 to 334 are pyramids, macrodomes, and brachydomes; in 335 to 349 the basal pinacoid is added.

Many of the above combinations include also prisms, macroprisms, and brachyprisms, but these planes cannot be shown by this mode of projection without lettering, as explained in Art. 70.

87. Hemihedral Forms.—These are of three kinds, viz.—

α. Forms with inclined faces (κhkl).

β. Forms with symmetrical faces (ςhkl).

γ. Forms with parallel faces (πhkl).

They consist of sphenoids, hemipyramids, and prisms.

88. Rhombic Sphenoids.—These are derived from the rhombic pyramids 111, figs. 228, 229, by a development of one-half the faces taken alternately. The relation of the positive sphenoid to the axes is shown in fig. 350, the sign of which is $\frac{111}{2}$ *Mitchell*, $\kappa 111$ *Miller*, $\frac{\text{P}}{2}$ *Naumann*. The negative sphenoid 351 has the signs $-\frac{111}{2}$ *Mitchell*, $\bar{\kappa}111$ *Miller*, $-{}^{\text{P}}$ *Naumann*.

Corresponding sphenoids may be obtained from every derived pyramid of each of the five orders described in Art. 75.

89. Hemipyramids.—A development of the group of four faces forming any solid angle of the rhombic pyramid 111, figs. 228, 229, produces a symmetrical form to which the sign ςhkl is given by Miller. The particular group of faces so developed is best indicated by Mitchell and Miller's symbols, which assign a particular modification of the general sign to each plane.

For the group of faces around the angle *k*, fig. 228, the full sign will be—

$$111,\ 11\bar{1},\ \bar{1}1\bar{1},\ \bar{1}11;\ \text{or}\ hkl,\ hk\bar{l},\ \bar{h}k\bar{l},\ \bar{h}kl,$$

in which the central member of the symbol of each face preserves its sign (+ or −) unchanged. The symbol here will be ςhkl. In like manner for the group of faces around the angle *l* the full sign will be—

$$111,\ \bar{1}11,\ \bar{1}\bar{1}1,\ 1\bar{1}1;\ \text{or}\ hkl,\ \bar{h}kl,\ \bar{h}\bar{k}l,\ h\bar{k}l,$$

in which the last member of the symbol of each face preserves its sign unchanged. The symbol here may be $\bar{\varsigma} hkl$.

Similar modifications of the general symbol may readily be arranged for the faces meeting at each solid angle. Each of the derived pyramids described in Art. 75 is subject to similar hemihedral modifications.

90. Hemihedral Prisms.—These are forms consisting of any two pairs of parallel faces of the pyramids 111 or *hkl*, fig. 228. They have the general symbol $\pi 111$ or πhkl, modified, as explained in Art. 87. Prisms are similarly produced from each of the brachydomes and macrodomes.

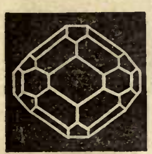


Fig. 342.

Fig. 343.

Fig. 344.

Fig. 345

Fig. 346.

Fig. 347.

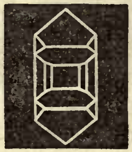


Fig. 348.

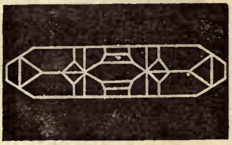


Fig. 349.

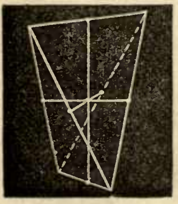


Fig. 350.

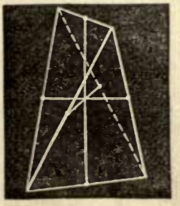


Fig. 351.

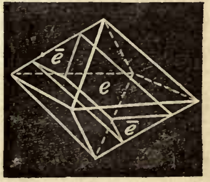


Fig. 352.

A combination of the positive and negative hemihedral developments of the pyramid hkl is given in fig. 352, where the large faces (e) belong to the form πhkl, and the small ones ($\bar{e}$) to $\bar{\pi} hkl$.


Fig. 353.

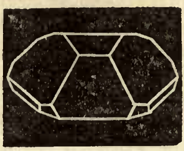


Fig. 354.

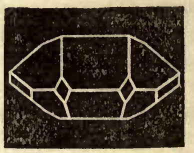


Fig. 355.

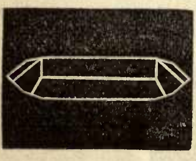


Fig. 356.

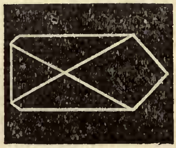


Fig. 357.

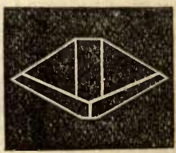


Fig. 358.


Fig. 359.

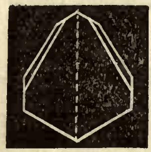


Fig. 360.


Fig. 361.


Fig. 362.

91. Vertical Projections of Hemihedral Forms.—These are given in figs. 353 to 362.

In the foregoing figures the following lettering is adopted. Planes parallel to—

$1 \infty \infty = 100 = a$
$\infty 1 \infty = 010 = b$
$\infty \infty 1 = 001 = c$
$1 1 \infty = 110 = m$
$1 1 1 = 111 = e$
$1 \infty 1 = 101 = v$
$\infty 1 1 = 011 = w$
$1 2 \infty = 120 = p$

$\infty 12 = 012 = s$ or w'
$\infty 1m = 01m = s'$ or w''
$\infty 1m' = 01m' = s''$ or w'''
$1 \infty m = d$ or v'
$n 1 \infty = n$
$1 \infty 2 = f$ or v''
$2 1 2 = y'$
$1 1 3 = g$

92. Sphere of Projection.—In fig. 363 the position of the chief poles of this system are indicated on the sphere of projection. The example chosen is the crystal of barytes given in fig. 364. The outline of the prism 11∞ (m) is indicated by a thick broken line. The poles of the various faces are indicated by dots, and lettered to correspond with the fig. 364.

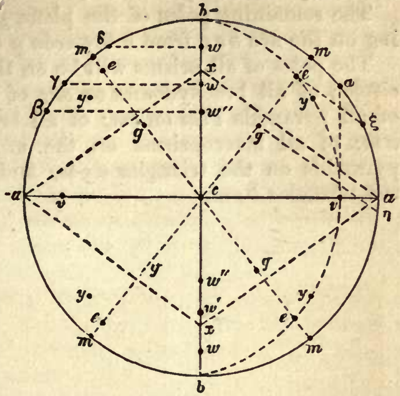


Fig. 363.

To draw the figure a circle is drawn with the centre c and any convenient radius $c\,a$, then the axial lines $a - a$, $b - b$, at right angles to each other.

The points $m\,m$ are then taken on the circumference of the circle, the angular distance $a\,m$ being 50° 50′, and the lines $m\,m$ are drawn through the centre c. These points m are the poles of the planes (11∞) m, fig. 364.

By drawing the dotted lines $a\,x$ at right angles to $c\,m$, we get a projection of the prism 11∞, the relative lengths of the lateral axes of which are as ca to $cx = 1{\cdot}227 : 1$.

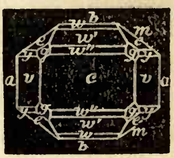


Fig. 364.

The poles of $v\,v$ are determined by measuring in the arc $a - b$ 37° 18′ towards $-b$, as at θ, and letting fall the perpendicular v on $a\,c$. The point v on the other side may be measured directly from c.

For the poles of the macrodomes w'', w', and w, the points β, γ, and δ, are taken in the arc $-a - b$ by measuring 28° 14′, 38° 52′, and 58° 10′ respectively, perpendiculars are then dropped as before.

For the poles of the planes $e\,e$, a point ε is taken in the same way on the arc $m\,\theta\,a$ towards a, making $m\,\varepsilon = 25° 42′$, and dropping the perpendicular εe; g is determined in the same way, only making $\eta = 55° 17'$.

The remaining poles of the plane y are found by measuring on the arc $b e v$ from b towards y 63° 58′.

The poles of all prisms will be on the circumference of the circle; of all brachydomes on *aa;* of all macrodomes on *bb;* of all pyramids 11*m* on *cm;* of all brachyprisms on the arcs *a m;* of all macroprisms on the arcs *b m;* of all brachypyramids on the triangles *a c m;* and of macropyramids on the triangles *b c m.*

CHAPTER XIII.

FORM (*Continued*)—THE OBLIQUE SYSTEM.

93. Axes, etc.—This system is so called because its forms may be derived from an oblique octahedron or an oblique prism. It has also been called *monoclinohedric, hemiprismatic, hemiorthotype, clinorhombic, hemihedric rhombic, two and one membered,* etc. There are three axes, two of which are at right angles to each other, the third inclined at different angles in different minerals. The lengths may be, and usually are, all different. One of the two axes which are at right angles is taken for the *principal,* the other is called *orthodiagonal,* while that which is inclined to the principal is termed the *clinodiagonal.*

94. Elements.—The variable conditions in this system are, the ratios of two axes to the third, and the inclination of the clinodiagonal to the principal. These conditions will be all defined if the following three angles, or their normals, be determined, viz., the angles made respectively by the planes 1∞1 with 1∞∞, 1∞1 with ∞∞1; and 111 with ∞1∞; (or, using Naumann's symbols, P∞ with ∞P∞; P∞ with 0P; and P with [∞ P∞]). The normals to these angles (α, β, γ, respectively), are the *angular elements* of the minerals in question, and $\alpha + \beta$ gives the inclination of the clinodiagonal to the principal axis.

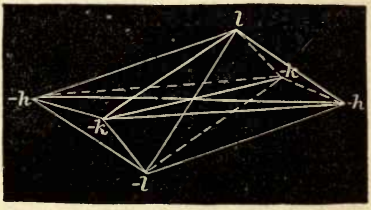


Fig. 365.

95. Oblique Pyramids.—The oblique rhombic octahedron, fig. 365, is bounded by eight scalene triangles in two sets of four, viz., four equal smaller triangles, and as many equal larger triangles. The four planes hkl, $\bar{h}k\bar{l}$, $h\bar{k}l$, $\bar{h}\bar{k}\bar{l}$, compose the form *h k l Miller* and P *Naumann.* This is called the positive hemipyramid. The four planes $\bar{h}kl$, $h\bar{k}\bar{l}$, $\bar{h}\bar{k}l$, $h\bar{k}l$, compose the form $\bar{h}kl$ *Miller*, – P *Naumann.* This is called the negative hemipyramid. Together, these two sets of planes compose the oblique rhombic pyramid, which is therefore a compound of two forms. The primary pyramid is, of course, that whose sign is 111 or $\bar{1}11$.

96. Derived Pyramids.—From the pyramids just described a series of derived pyramids may be derived, similar in position, but differing in magnitude. These may be conveniently arranged in three classes, viz.:—

1st Class.—By multiplying the principal axis by any number m, greater or less than unity, a series of new positive and negative hemipyramids are obtained, the symbols of which are $11m$ and $\bar{1}1m$ *Mitchell*, mP and $-m$P *Naumann.*

2nd Class.—By multiplying the principal axis by any number m, and the orthodiagonal by any number n, we obtain a second series of positive and negative hemipyramids, the symbols of which are $1nm$ and $\bar{1}nm$ *Mitchell;* $m\mathrm{P}n$ and $-m\mathrm{P}n$ *Naumann.*

3rd Class.—Multiplying the principal axis by any number m, and the clinodiagonal by any number n, we obtain a third series of positive and negative hemipyramids, the symbols of which are $n1m$ and $\bar{n}1m$ *Mitchell;* $(m\mathrm{P}n)$ and $-(m\mathrm{P}n)$ *Naumann.*

97. Open Forms.—These result when either h, k, or l, or any two of them become zero. Some have two planes, some have four, but of themselves they cannot form a complete figure. A large number of oblique prisms are produced by their combinations with each other, some of which have rhombic and some rectangular bases.

98. Oblique Rhombic Prisms.—These are of several kinds, as follows:—

1st Order.—This includes two distinct "forms," viz., the form 11∞ *Mitchell*, 110 *Miller*, ∞P *Naumann*, having four faces, and the basal pinacoid $\infty\infty1$, 001, or 0P, having two faces. From this prism two classes of derived prisms may be obtained, similar in position, but differing in dimensions; the first class by multiplying the orthodiagonal axis by any number greater or less than unity, producing the prism

1*m*∞, ∞∞1; and the second class by similarly multiplying the clinodiagonal, producing the prism *m*1∞, ∞∞1.

2nd Order.—These are combinations of the four planes of the clinodome ∞11 *Mitchell,* 011 *Miller,* (P∞) *Naumann,* with the orthopinacoid 1∞∞ *Mitchell,* 100 *Miller,* ∞P∞ *Naumann.*

From this prism a new series may be derived by multiplying the principal axis by any number more or less than unity, producing the prism ∞1*m*, 1∞∞.

99. **The Oblique Rectangular Prism.**—This includes three forms, viz., orthopinacoids 100 *Miller;* ∞P∞ *Naumann* (*a*); the clinopinacoids 010 *Miller,* (∞P∞) *Naumann* (*b*); and the basal pinacoids 001 *Miller,* 0P *Naumann* (*c*).

100. **Right Prism on Oblique Rhombic Base.**—This prism consists of the positive orthodome 1∞1 *Mitchell,* 101 *Miller,* P∞ *Naumann* (*v*); the negative orthodome $\bar{1}\infty 1$ *Mitchell,* $\bar{1}01$ *Miller,* −P∞ *Naumann;* and the clinopinacoid ∞1∞ *Mitchell,* 010 *Miller,* (∞P∞) *Naumann.*

A series of derived pyramids may be obtained from this prism also by multiplying the principal axis, when the symbols will become 1∞*m*, $\bar{1}\infty m$, ∞1∞.

101. **Pseudoprisms.**—It is evident that if the four planes of the positive hemipyramid hkl, $\bar{h}k\bar{l}$, $h\bar{k}l$, $\bar{h}\bar{k}\bar{l}$, are present in any crystal to the exclusion of the negative hemipyramid, or *vice versa,* the resulting figure will have all the appearance of, and, in fact, will be a rhombic prism. This will be still more striking if the ends happen to be closed by pinacoids. To distinguish such forms from the true prisms it will be well to name them as I have done.

Whatever the appearance of the combination, the symbols will, of course, be those belonging to the respective hemipyramids.

102. **Hemihedral Forms.**—These may, of course, be produced by the development of contiguous faces in pairs in any of those "forms" which have four planes, *i.e.*, hkl, $\bar{h}kl$, 11∞, 1*m*∞, *m*1∞, ∞11, or ∞1*m*. They may very well be indicated by prefixing the sign σ to the symbol of the form in question, or in the manner constantly adopted by Naumann, thus $\frac{111}{2}$.

It should, however, be noted that the sign σhkl and $\bar{\sigma} hkl$ have been specially applied to those pairs of faces in the hemi-pyramids hkl and $\bar{h}kl$, where k has the same sign, whether positive or negative. Thus in fig. 366 σhkl will indicate the pair of planes *ee*, and $\bar{\sigma} hkl$ will indicate *i i*. Rhombic sphenoids may result from a combination of the planes hkl, $hk\bar{l}$ with the planes $\bar{h}\bar{k}l$, $h\bar{k}\bar{l}$; or of the remaining four planes of the oblique octahedron.

In fig. 365 the crystal is projected in a plane parallel to the principal, but not parallel either to the orthodiagonal or clinodiagonal axes. In the *following* figures the plane of projection is parallel to the principal and clinodiagonal, and normal to the orthodiagonal.

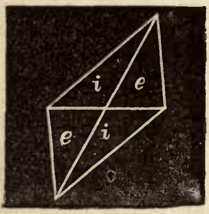


Fig. 366.

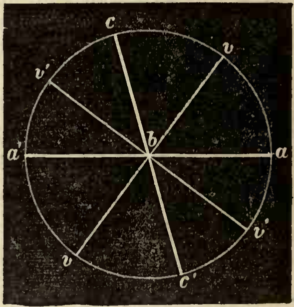


Fig. 367.

103. Sphere of Projection.—To draw a map of the sphere of projection for this system on the projection last described take *b* as a centre, fig. 367, and draw a circle of any convenient radius with *ba* as a radius.

Let *aa'* be a diameter, preferably horizontal. Then make ac = as many degrees as $\alpha + \beta$ (Art. 92). Then aa' = poles of the orthopinacoids $1 \infty \infty$, $\bar{1} \infty \infty$; *b* is the pole of the clinopinacoid $\infty 1 \infty$; and *c* that of the basal pinacoid $\infty \infty 1$. Bisect *ac* in *v*, and draw *vbv*. Then *vv* are the poles of the positive orthodomes $1 \infty 1$, $\bar{1} \infty \bar{1}$. Bisect *a'c* in *v'*, draw *v'bv'*; *vv'* are the poles of the negative orthodomes. The poles of the clinodomes will fall on *bc* and *bc'*; those of the positive hemipyramid 111 on *bv*, *bv* of the negative hemipyramid $\bar{1}11$ on *bv′*, *bv′*.

In fig. 368 is given a complete crystal of humite or chondrodite, the poles of the planes of which are marked on fig. 369.

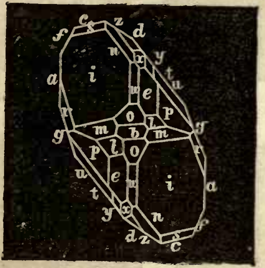


Fig. 368.

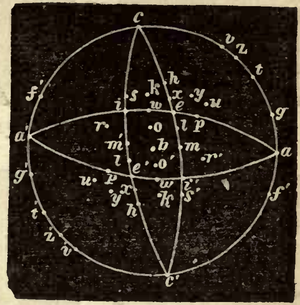


Fig. 369.

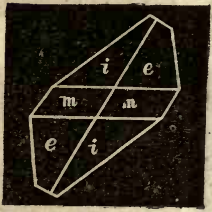


Fig. 370.

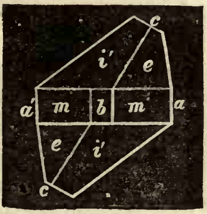


Fig. 371.

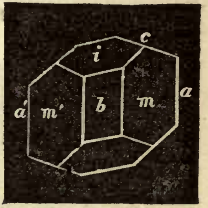


Fig. 372.

104. Combinations.—A series of combined forms in the oblique system is given in figs. 370 to 419, which the student will do well to study. Figs. 370 to 389 represent crystals where $\alpha+\beta$ is less than 90°; in the following figures, 390 to 419, the angle $\alpha+\beta$ is usually more than 90°. The lettering adopted for all the figures is as follows:—

For the plane	1∞∞	*a*	for	1∞1	*v*
,,	∞1∞	*b*	,,	$\bar{1}\infty 1$	*h* or *v′*
,,	∞∞1	*c*	,,	∞11	*w*
,,	11∞	*m*	,,	$\bar{\infty}11$	*w′*
,,				12∞	*f*
,,	111	*e*		131	*j*
,,	$\bar{1}11$	*i*			

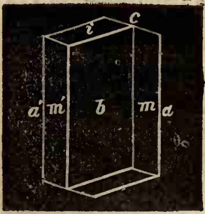


Fig. 373.

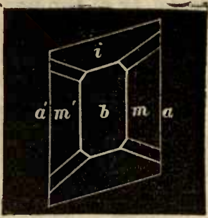


Fig. 374.

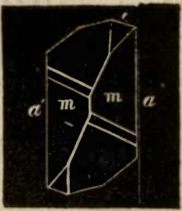


Fig. 375.

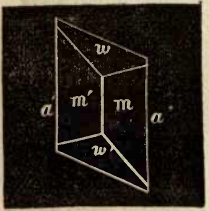


Fig. 376.

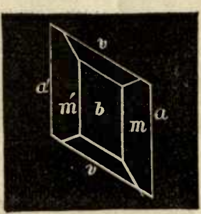


Fig. 377.

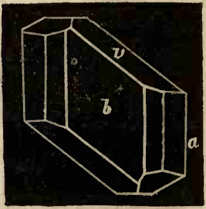


Fig. 378.

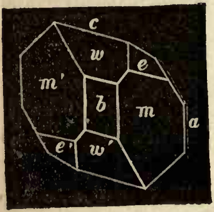


Fig. 379.

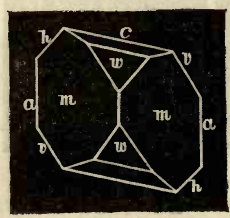


Fig. 380.

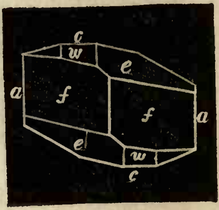


Fig. 381.

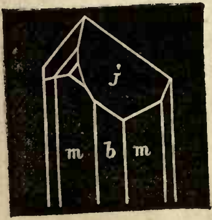


Fig. 382.

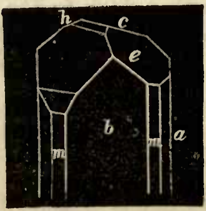


Fig. 383.

Fig. 384.

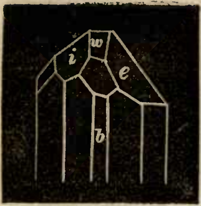


Fig. 385.

Fig. 386.

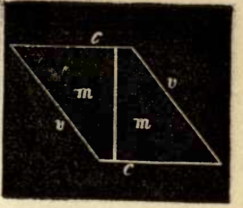


Fig. 387.

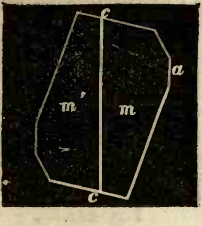


Fig. 388.

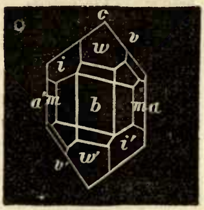


Fig. 389.

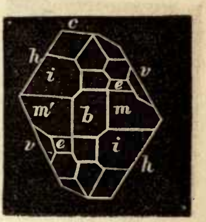


Fig. 390.

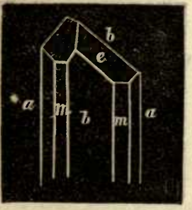


Fig. 391.

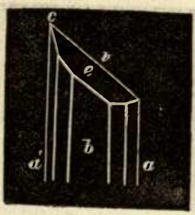


Fig. 392.

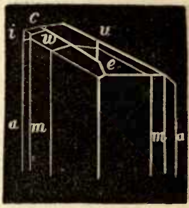


Fig. 393.

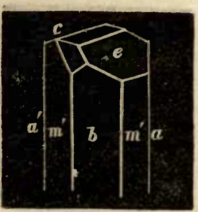


Fig. 394.

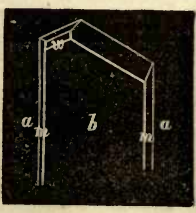


Fig. 395.

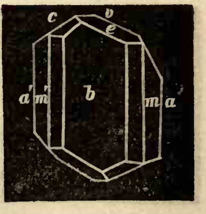
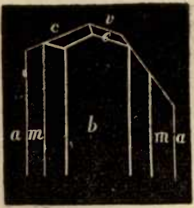


Fig. 396.



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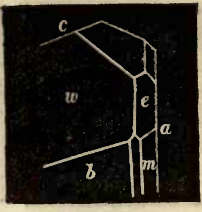

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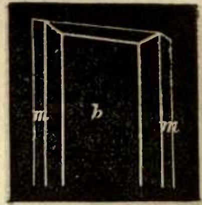

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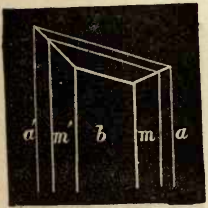

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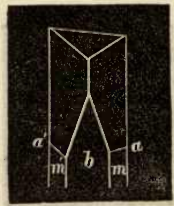

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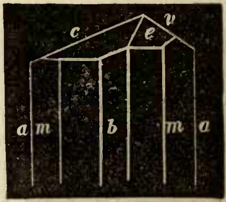

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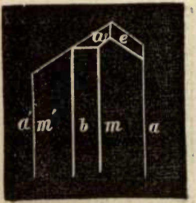

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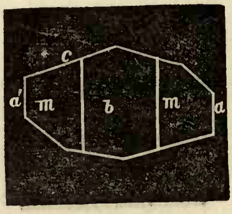

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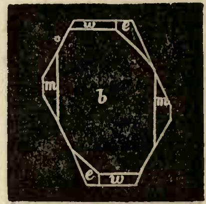

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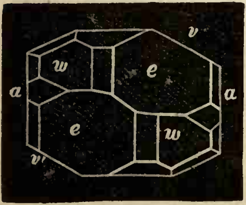

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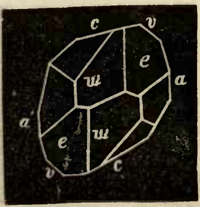

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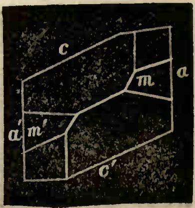

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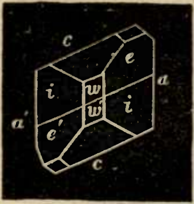

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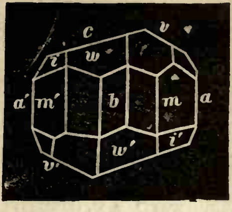

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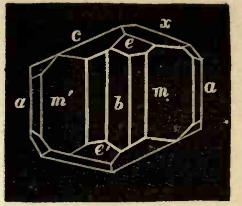

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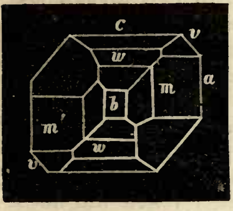

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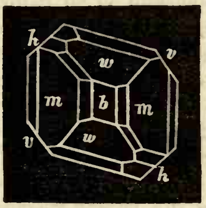
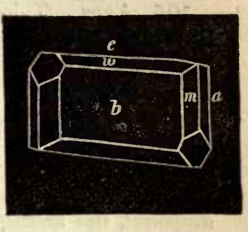


Fig. 413.



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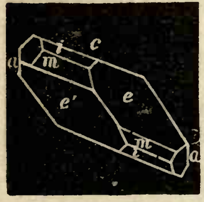


Fig. 415.

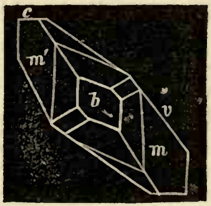


Fig. 416.

Fig. 417.

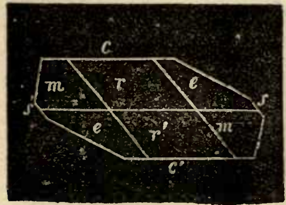


Fig. 418.

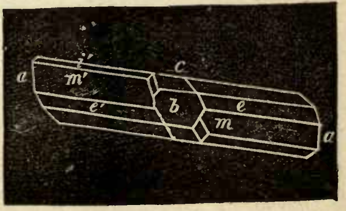


Fig. 419.

CHAPTER XIV.

FORM (*Continued*)—THE ANORTHIC SYSTEM.

105. Axes.—This system is so called (*α* and *ορθοσ*), on account of the extremely irregular character of the crystals belonging to it. Other names are *doubly-oblique*, *triclinohedric*, *anorthotype*, *one and one membered*, *tetartorhombic*, *tetartoprismatic*, etc. There are three axes which are of various lengths, and inclined to each other at various angles. Either of them may be taken for the principal, when the longer of the remaining axes may be called the *macrodiagonal*, the shorter the *brachydiagonal*. When the axes are nearly at right angles the forms may superficially resemble those of the rhombic system, when two only are nearly at right angles they will resemble those of the oblique system.

106. Elements.—The variable conditions in this system are evidently five, viz., the lengths of two axes as compared with the third and the angles between the various axes. These elements may be determined by spherical trigonometry, when the poles of any five planes lying in not less than three zones are known, but the most convenient poles are the following, viz., 1∞∞, ∞1∞, ∞∞1, 1∞1, ∞11. Thus, in axinite the normals to the angles formed by planes to which these poles respectively belong are:—

∞∞1 1∞∞ = 56° 55′
∞∞1 1∞∞ = 97° 46′
∞∞1 ∞11 = 44° 43′
∞∞1 ∞1∞ = 89° 55′
1∞∞ ∞1∞ = 77° 30′.

107. Doubly Oblique Pyramids.—Much ingenuity has been expended in describing these, but they rarely if ever occur in nature, and it is better to regard them as combinations of several distinct forms, each consisting of a pair of similar planes oppositely situated as regards the centre of the crystal.

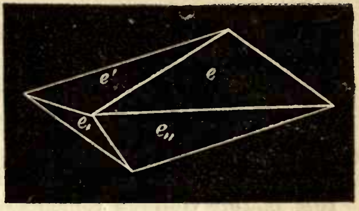


Fig. 420.

Thus the doubly oblique octahedron, fig. 420, is a solid bounded by four pairs of equal and similar scalene triangles. These octahedrons are regarded as combinations of the four forms composed of the planes e, e', $e_,$, ${}_{,,}e$ (with their respective opposite planes). These forms taken separately are called tetarto-pyramids.

The general symbol of the whole octahedron may be *hkl*, that of Naumann is P. The symbols of the various separate forms are:—

FORM.	*Mitchell* and *Miller*.	*Naumann*.
$111\ \bar{1}\bar{1}\bar{1}$	111	P^1
$\bar{1}11\ 1\bar{1}\bar{1}$	$\bar{1}11$	${}^1P$
$11\bar{1}\ \bar{1}\bar{1}1$	$11\bar{1}$	P_1
$\bar{1}1\bar{1}\ 1\bar{1}1$	$\bar{1}1\bar{1}$	${}_1P$

Of course, octahedrons of several distinct kinds may be derived from these by lengthening or shortening either one or two of the parameters, as already described under the oblique system; but as there are very few minerals crystallizing in this system — less than a dozen whose forms have been numerically determined — we need not devote any space to them here.

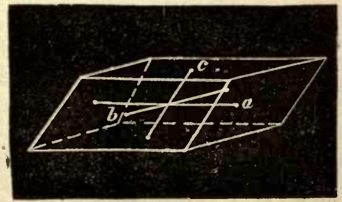


Fig. 421.

108. Doubly Oblique Prisms. — These also are best studied as combinations of open forms. Fig. 421 represents the doubly oblique prism of 2nd order with its axes, where the plane a is one plane of the form $\breve{1}\infty\infty$ (or the *brachy-*

pinacoid), *b* of the form $\infty\bar{1}\infty$ (or the *macropinacoid*), *c* of the form $\infty\,\infty 1$, or the *basal pinacoid*. The symbols are as follows:—

Brachypinacoid,	$1\infty\,\infty$ *Mitchell*,	100 *Miller*,	$\infty\breve{P}\infty$ *Naumann*.
Macropinacoid,	$\infty 1\infty$ *Mitchell*,	010 *Miller*,	$\infty\bar{P}\infty$ *Naumann*.
Basalpinacoid,	$\infty\,\infty 1$ *Mitchell*,	001 *Miller*,	OP *Naumann*.

Derived oblique prisms are of many kinds, indeed any three pairs of planes whose poles do not all lie in the same zone circle may produce such a prism.

109. Doubly Oblique Sphenoids.—These are produced by the development of one-half the planes of the doubly oblique octahedron alternately, *i.e.*, they are combinations of two forms instead of four. They rarely occur in nature, and there would be little advantage in devoting space to their study here.

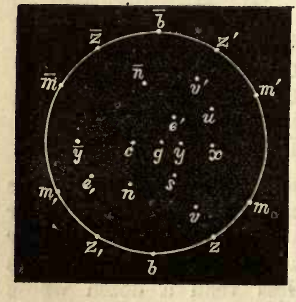


Fig. 422.

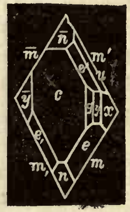


Fig. 423.

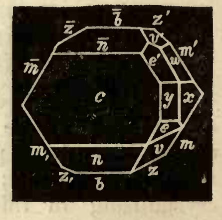


Fig. 424.

110. Sphere of Projection.—This is drawn in various positions, according to the peculiar character of the crystals to be illustrated. In general the figures of this system are best projected on a plane, perpendicular to the axis of the zone $1\infty\,\infty$, $1\infty 1$, by lines parallel to that axis. Fig. 422 is the sphere of projection of *anorthite* drawn in this manner. The poles of the zone just referred to fall then on the circle, while that of the plane $\infty\infty 1$ is seen near the centre at *c*.

Figs. 423 and 424 are crystals of *anorthite*, whose poles are indicated by the dots in fig. 422. Figs. 423 to 430 are all drawn on the same projection. In figs. 431 to 433 a different projection is chosen, in order to show numerous small planes which would not otherwise be very well seen.

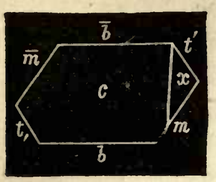


Fig. 425.

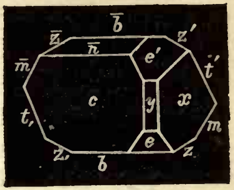


Fig. 426.

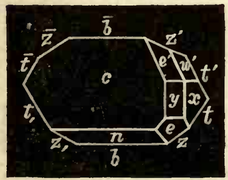


Fig. 427.

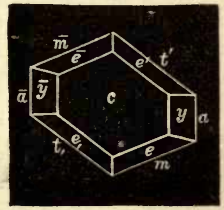


Fig. 428.

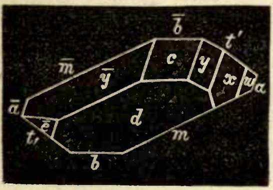


Fig. 429.

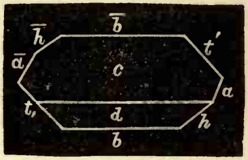


Fig. 430.

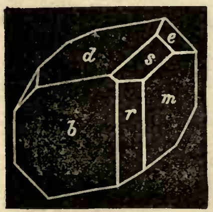


Fig. 431.

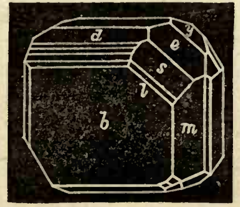


Fig. 432.

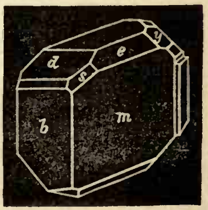


Fig. 433.

In all the figures the various symbols are indicated by the same letters, viz.:—

$1\infty\infty = a$
$\bar{1}\infty\infty = \bar{a}$
$\infty 1\infty = b$
$\infty\bar{1}\infty = \bar{b}$
$\infty\infty 1 = c$
$111 = e$
$\bar{1}\bar{1}1 = \bar{e}$
$1\bar{1}1 = e'$
$\bar{1}11 = e_{,}$
$11\infty = m$
$\bar{1}\bar{1}\infty = \bar{m}$
$1\bar{1}\infty = m'$
$1\bar{1}\infty = m_{,}$
$1\infty 1 = y$
$\bar{1}\infty 1 = \bar{y}$
$121 = s$

$12\infty = r$
$13\infty = z$
$\bar{1}\bar{3}\infty = z$
$1\bar{3}\infty = z'$
$1\bar{3}\infty = z_{,}$
$131 = i$
$2\infty 1 = x$
$2\infty 3 = g$
$\infty 11 = d$
$21\infty = h$
$2\bar{1}\infty = \bar{h}$
$\infty 21 = n$
$\infty\bar{2}1 = \bar{n}$
$221 = u$
$241 = v$
$301 = w$

CHAPTER XV.

FORM (*Continued*)—THE HEXAGONAL SYSTEM.

111. Axes, etc.—This system is so called because of the numerous hexagonal prisms which occur in it. It is also called *rhombohedral* because of its numerous rhombohedrons, and *monotrimetrical* and *three and one axial* from the properties of its axis. There are four axes, three of which lie in one plane, are inclined to each other 60°, and are of equal length, while the fourth is at right angles to them, passes through their intersections, and is of variable length. The three equal axes are called *lateral*, the fourth axis *principal.**

112. Angular Element.—The angle made by the principal axis with the *normals* to the planes of the chief pyramid occurring in any particular substance crystallising in this system is called the *angular element* of that substance, as described in Art. 56. It is the only variable element in the system, and from it the typical forms and the lengths of the axes or perameters may be derived. The angular element differs widely in different minerals, from 27° 20′ in *tourmaline* to 81° 20′ in *parisite*.

113. Holohedral Forms—Pyramids.—These are of three orders as follows:—

---

* Professor Miller refers the forms of the "rhombohedral" system to three axes which coincide with the *normals* to the planes of the *principal rhombohedrons*. These three axes will be, of course, of equal length, and equally inclined to each other, but their inclination will differ in each particular substance, and will depend upon its angular element. This system is more consistent with those already described for the other systems, and is decidedly better for calculation. But the system of four axes is believed to give in its formulæ a clearer view of the relations of the various forms to each other; besides which the principal axis is of great natural importance, as it is the optic axis of all the transparent substances crystallising in the systems.

1. Double six-faced pyramid of 1st order. This form is bounded by twelve equal isosceles triangles; each plane cuts two of the lateral axes at equal distances from the centre, and the principal axis at its extremity. The symbol therefore is 111. Fig. 434 shows the situation of the axes in a crystal where the principal axis is much longer than the laterals, fig. 440 where it is very little longer. The symbols of this form will be 111 *Mitchell*, P *Naumann*. Brooke and Miller regard this pyramid as a combination of the two distinct rhomboids which will be described hereafter as its hemihedral forms. The situation of the axes, as viewed from above, is seen in fig. 435.

2. Double six-faced pyramid of 2nd order. This also is bounded by twelve equal isosceles triangles, it only differs from that just described in the position of the lateral axes; fig. 436 shows the situation of the axes in the pyramid of second order, the symbols of which are 121 *Mitchell*, 521 *Miller*, P2 *Naumann*. Each plane cuts the principal axis and one lateral axis at normal distances from the centre, and two other lateral axes (prolonged) at twice the normal distance, as shown at *aa*. A double six-faced pyramid *third order* will be described later as a hemihedral form,

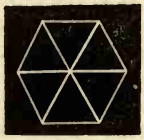


Fig. 435.

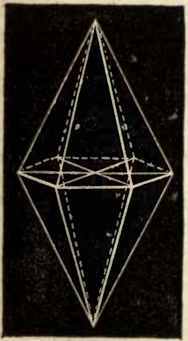


Fig. 434.

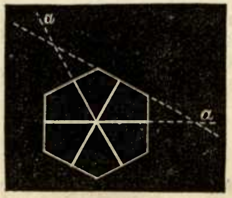


Fig. 436.

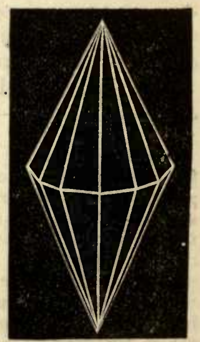


Fig. 437.

114. Derived Pyramids.—From each of the orders of pyramids just described a series of pyramids may be derived by multiplying the principal axis by any number greater or less than unity. For derived pyramids of the 1st order the general symbols will be 11m *Mitchell*, Pm *Naumann;* for those of the second order 12m *Mitchell*, mP2 *Naumann*, *hkl Miller.*

115. Prisms.—Each order of pyramids has its corresponding hexagonal prism which results when the principal axis is multiplied by infinity. Figs. 435 and 436 serve to show the situation of the lateral axes in the two orders of hexagonal prisms. A third order of hexagonal prisms will be described hereafter as a hemihedral form.

The symbols for those of the 1st order are 11∞ *Mitchell*, ∞P *Naumann*, $2\bar{1}\bar{1}$ *Miller;* for the 2nd order 12∞ *Mitchell*, ∞P2 *Naumann*, $0\bar{1}1$ *Miller.* These prisms are really open or incomplete forms, they may be regarded as combinations of the planes just described with the basal pinacoids ∞ ∞1 *Mitchell*, 0P *Naumann*, 111 *Miller.*

116. Dihexagonal Pyramids.—These are bounded by twenty-four equal *scalene* triangles, as shown in fig. 437, but they are not known to occur as complete forms in nature, the symbols are 1mn *Mitchell*, mPn *Naumann.* The situation of the lateral axes is shown in fig. 438; when $m = 2$ it might be mistaken for a combination of the pyramids of 1st and 2nd order.

Fig. 438.

117. Dihexagonal Prism.—This is an open form, having the same relation to the dihexagonal pyramid as the hexagonal prisms have to the double six-faced pyramids. The symbols are 1n∞ *Mitchell*, ∞Pn *Naumann.* The situation of the lateral axes may be seen in fig. 438.

118. Sphere of Projection.—With C as centre, and any convenient radius, draw the circle M_1, G_1, etc., fig. 439. Starting from M_1, mark off M_2, etc., equal to the radius. Join M_1, M_4; M_2, M_5; M_3, M_6; then the lines so produced will represent the lateral axes of the crystal, and the point C the pole of the plane ∞ ∞1, *i.e.*, the north pole of the sphere of projection, while M_1, M_2, etc., will be the poles of the planes 121 situated on the equator; bisect each of the arcs M_1, M_2, etc., in G_1, G_2, etc., then the points G will be the poles of the planes 11∞; those of $1m1$ will lie between m and G on the equator, the actual position depending upon the value of m. The poles of the pyramids $11m$ will lie on the lines G, c, etc., those of the pyramids $12m$ on the lines M_1, c, etc., those of the dihexagonal pyramids $1mn$ within the spaces M, G, c, the positions varying with the angular element of the crystal and the value of m or n.

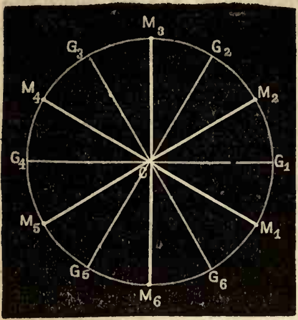


Fig. 439.

119. Hemihedral Forms.—These are of two kinds, those with *parallel* and those with *inclined* faces. The parallel-faced forms are the rhombohedrons, derived from the double six-faced pyramids of 1st and 2nd orders; the double six-faced pyramid of 3rd order; the hexagonal scalenohedron derived from the dihexagonal pyramid; and the hexagonal prism of 3rd order derived from the dihexagonal prism.

The hemihedral forms with inclined faces are the double three-faced pyramid, derived from the double six-faced pyramids of 1st and 2nd orders; the double six-faced trapezohedron from the dihexagonal pyramid; and the triangular prism from the hexagonal prisms of 1st and 2nd order.

120. Rhombohedrons.—These are hemihedral forms of the double six-faced pyramids, and they occur in series corresponding with the different pyramids. For each pyramid there are two rhombohedrons, distinguished as positive and negative. Thus, figs. 441 and 442 represent the rhombohedrons derived from the pyramid 111, fig. 440. The positive, fig. 441, corresponding with the shaded planes in fig. 440, the negative with the unshaded planes. The rhombohedrons are bounded by six equal rhombic planes, having twelve equal edges. If we place one so that the two three-faced solid angles which are formed by the union of equal angles of the rhombic faces are upright, its principal axis will then be vertical as it joins these angles. In the rhombohedron derived from the pyramid of 1st order the lateral axes will then join the central points of those edges which are not polar, *i.e.*, which do not form part of the three-faced solid angles just mentioned. The symbols are $\pm\left[\frac{111}{2}\right]$ *Mitchell;* $\pm\frac{P}{2}$ or ± R *Naumann.* Miller's symbol for the *positive* rhombohedron is 100; for the *negative* rhombohedron $\ddot{1}22$.

Similar rhombohedrons may be similarly derived from all the other double six-faced pyramids, *i.e.*, by developing the planes alternately. Their symbols will be those of the respective pyramids modified as above.

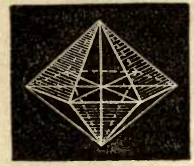


Fig. 440.

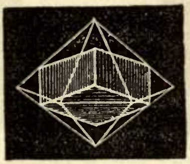


Fig. 441.

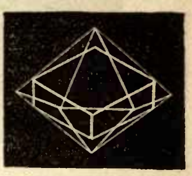


Fig. 442.

121. Scalenohedrons.—These are derived from the dihexagonal pyramids by developing alternate pairs of faces, the upper pairs also alternating with the lower ones. Like the rhombohedrons they may be either positive or negative. Figs. 443 and 444 show the positive and negative scalenohedrons derived from the dihexagonal pyramid, fig. 437.

The lateral edges of the scalenohedrons correspond with the edges of certain rhombohedrons which may be inscribed within them, as in figs. 445 and 446. The symbols are derived from those of the dihexagonal pyramid in the usual manner. It is evident that the principal axis of the scalenohedron must have a certain ratio to that of the inscribed rhombohedron; this ratio is often simple, *i.e.*, it may be 2, 3, 4, etc., times as long. This being the case its general symbol is sometimes written 2R, 3R, 4R, etc. Miller's symbol for the scalenohedrons is $\pi\{hkl.\}$

122. Double Six-faced Pyramids of 3rd Order.—If the alternate upper planes of the dihexagonal pyramid are produced to meet the *corresponding* lower planes and the other planes are suppressed, the resulting form will differ only in the position of its lateral axes from those of the 1st and 2nd orders; by making the principal axis equal ∞ a hexagonal prism of 3rd order results. From these 3rd order pyramids rhombohedrons and double three-faced pyramids may be produced by developing alternate planes only, but these will be tetartohedral forms.

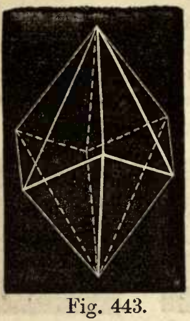


Fig. 443.

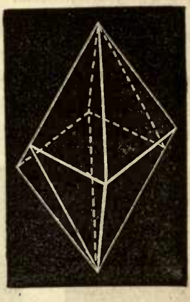


Fig. 444.

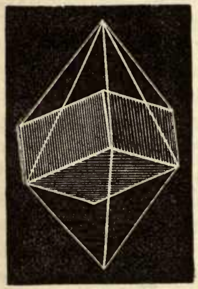


Fig. 445.

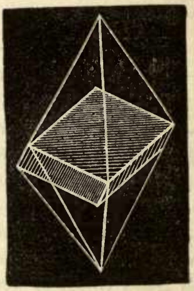


Fig. 446.

123. The Double Six-Faced Trapezohedron is produced by developing alternate upper planes of the dihexagonal pyramid and *opposite* alternate lower planes. The resulting figure is a double six-faced trapezohedron. By developing one-half of these planes alternately we obtain a double three-faced trapezohedron, which is also a tetartohedral form.

From the double six-faced pyramids of 1st, 2nd, and 3rd orders, double three-faced pyramids may be obtained by developing alternate upper planes and their corresponding lower planes. In the case of the 1st and 2nd orders of pyramids they will be *hemihedral* in that of the 3rd order they will be *tetartohedral* forms.

124. Three-faced Prisms.—From the hexagonal prisms of all three orders triangular prisms may be produced by developing alternate planes. Those so produced from prisms of 1st and 2nd order will be *hemihedral,* those from the 3rd order are *tetartohedral* forms.

125. Combinations.—In the following figures 457 to 475 the lettering indicates planes having symbols as below:—

C = ∞∞1
M = 128
G = 11∞
R = $+\left[\frac{111}{2}\right]$
$\bar{R}$ = $-\left[\frac{111}{2}\right]$
z = $+\left[\frac{12m}{2}\right]$

$\bar{z}$ = $-\left[\frac{12m}{2}\right]$
d = 11*m*
e = 12*m*
f = 1*m*∞
g = 1*mn*

126. Prisms and Pyramids.—Fig. 447 is the pyramid and prism 111 + 11∞; fig. 448 the same with the addition of ∞∞1; fig. 449 is the pyramid 111 with the prism 12∞; fig. 450 two pyramids of 1st order 11*m* (*d* and *d'*); one pyramid of 2nd order (*e*); the prism of 1st order 11∞ (G); prism of 2nd order 12∞ (M), and the basal plane ∞∞1 (*c*); fig. 451 shows a pyramid of 1st order 11*m* (*d*); prism of 1st order 11∞ (G); of 2nd order 12∞ (M); the dihexagonal prism 1*mn* (*f*), and the basal plane ∞∞ 1 (*c*).

127. Prisms and Rhombohedrons.—Fig. 452 is a combination of the positive rhombohedron $\left[\frac{111}{2}\right]$ with the hexagonal prism 12∞; fig. 453 is the same with the chief axis increased, and rather differently placed; fig. 454 is the prism 11∞ with the rhombohedron $\left[\frac{11m}{2}\right]$; fig. 455 is the prism 12∞ with the same rhombohedron; fig. 456 the same with the addition of the rhombohedron $\left[\frac{12m}{2}\right]$; fig. 457 is the rhombohedron $\left[\frac{111}{2}\right]$ with the rhombohedron $\left[\frac{112}{2}\right]$; fig. 458 the rhombohedrons $\left[\frac{112}{2}\right]$ and $-\left[\frac{111}{2}\right]$.

128. Rhombohedrons and Scalenohedrons.—Fig. 459 is the prism 11∞, the prism 12∞, the rhombohedron $\left[\frac{11m}{2}\right]$, another rhombohedron $\left[\frac{11m}{2}\right]$, and the scalenohedron 1*mn;* fig. 460 is a rhombohedron $\left[\frac{11m}{2}\right]$, with the scalenohedron 1*mn.*

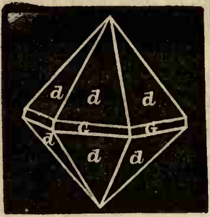


Fig. 447.

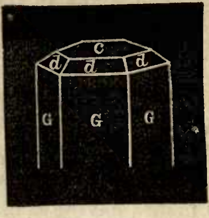


Fig. 448.

Fig. 449.

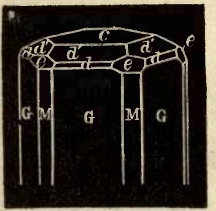


Fig. 450.

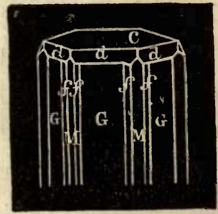


Fig. 451.

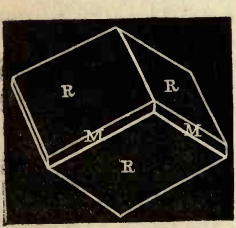
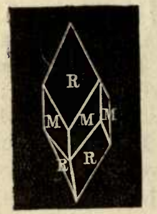


Fig. 452.



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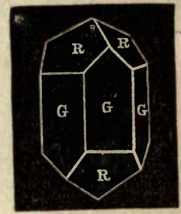

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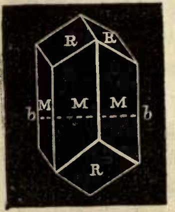

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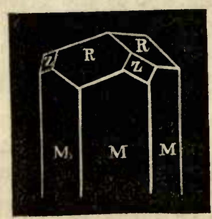

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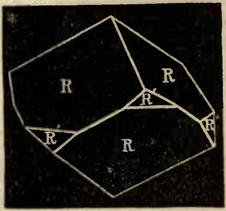


Fig. 457.

Fig. 461 is a rhombohedron and scalenohedron; fig. 462 a scalenohedron and prism; fig. 463 a scalenohedron and prism of different order.

Fig. 458.

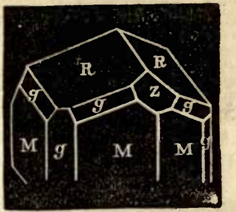


Fig. 459.

Fig. 460.

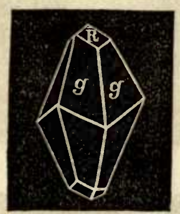
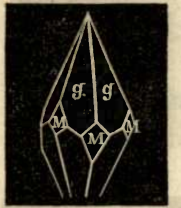


Fig. 461.

Fig. 462.



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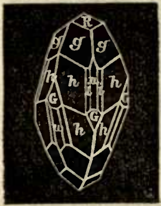


Fig. 464.

Fig. 465.

Fig. 464 is a very complex crystal of calcite, in which the following planes appear:—

R, the rhombohedron $\left[\frac{111}{2}\right]$ = R *Naumann*
u, ,, $\left[\frac{114}{2}\right]$ = 4R ,,
g, the scalenohedron = R^3 ,,
h, ,, = R^5 ,,
i, ,, = $\frac{8}{5}R^3$,,
G, the prism 11∞ = ∞P ,,

Fig. 465 is a complex crystal of quartz, showing the following planes—

d, *d′*, *d″*, *d″*,	Four pyramids of 1st order.
s,	A three-faced pyramid.
w, *v*, *w*, *x*,	Four double three-faced trapezohedrons.
M,	Planes of the prism 12∞.

The following series of figures 466 to 497 is projected on a plane perpendicular to the principal axis by lines parallel to that axis, and at right angles to the plane of projection, according to the plan adopted by Messrs Brooke and Miller.


Fig. 466.

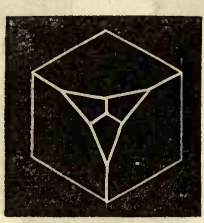


Fig. 467.

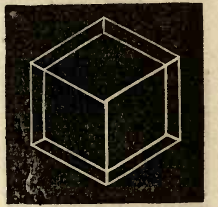


Fig. 468.


Fig. 469.


Fig. 470.


Fig. 471.

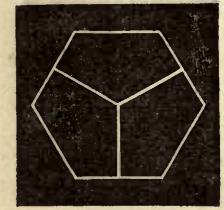


Fig. 472.


Fig. 473.


Fig. 474.

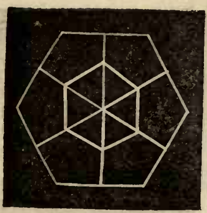


Fig. 475.

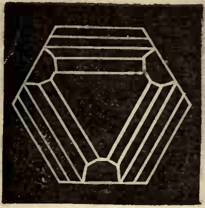


Fig. 476.

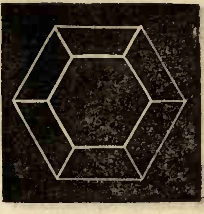
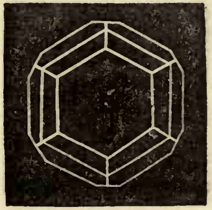


Fig. 477.

Fig. 478.



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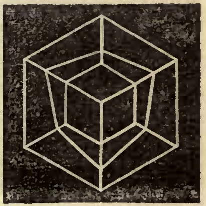


Fig. 480.

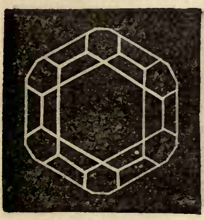
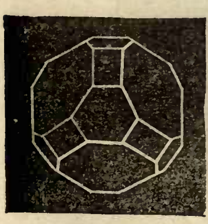


Fig. 481.

Fig. 482.

Fig. 483.



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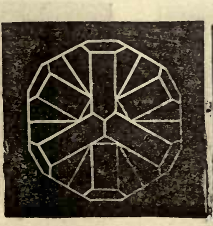

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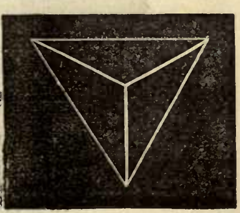

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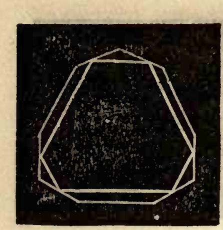


Fig. 487

Fig. 488.

Fig. 489.

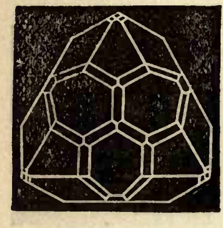
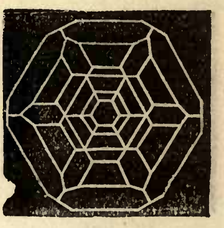


Fig. 490.

Fig. 491.



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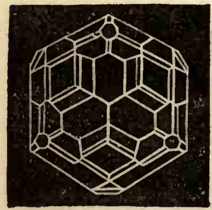


Fig. 493.

Fig. 494.

Fig. 495.

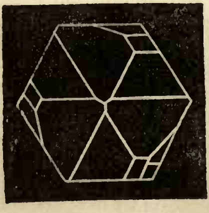


Fig. 496.

Fig. 497.

In the foregoing description of the hexagonal system, we have but rarely given the symbols adopted by Professor Miller, because there is seldom anything like a parallelism between them and the symbols used by Mitchell or Naumann, owing to the totally different axes employed in the two cases. But we may here note the symbols of the planes indicated below, which will serve as keys to the interpretation of the forms most likely to be met with, viz.:—

Mitchell	*Naumann*	*Miller*
Form 111	= P	= $100+\bar{1}22$
,, $11m$	= mP	= lkk
$\pm\left[\frac{111}{2}\right]$	= $\pm$R or $\pm\frac{P}{2}$	= 100
,, 12∞	= ∞P_2	= $01\bar{1}$
,, 11∞	= ∞P	= $2\bar{1}\bar{1}$
,, $\infty\infty 1$	= 0P	= 111
121	= P_2 or $R\infty$	= 521
$12m$	= $mP2$ or $mR\infty$	= hkl
$\pm\left[\frac{11m}{2}\right]$	= $\frac{mP}{2}$ or mR	= hkk
$1n\infty$	= ∞Pn	= hkl
$1mn$	= mPn	= hkl
$\pm\left[\frac{1mn}{2}\right]$	= $\pm\left[\frac{mPn}{2}\right]$	= πhkl

CHAPTER XVI.

OF MACLES AND THE IRREGULARITIES OF CRYSTALS.

129. **Macles, Twin-crystals,** or **Hemitropes,** are groups of two or more crystals, which appear as if mutually intersecting each other, or sometimes as if a single crystal had been cut in two in a certain direction, one part turned round a certain number of degrees, and then re-united. The axis around which the portions move, or may be supposed to move, is called the *twin-axis,* and the plane of movement the *twin-plane.* Thus, if the octahedron, fig. 498, be cut in two, in the direction of the dotted line or twin-plane *b b,* one-half rotated on the axis *c c* through 90°, and the two again united, a macle like fig. 499 will result, a form which is frequently met with in *spinel, alum,* and other minerals. Of course, no such division and re-union has really taken place; the whole crystal having taken that form from its first origin.

Little is known of the crystallising forces, and almost nothing of that branch which leads to the formation of twin-crystals, but the results of this action are very common, and it is found that the twin-axes of macles are always inclined to each other, and to the principal axes of the different parts, in certain definite directions for each mineral species, the crystals of which affect the macled form.

130. **Cubical Macles.**—Figs. 498 to 505 are macles occurring in the cubical system. Figs. 498 and 499 have already been referred to. In fig. 500 the twin-planes are parallel to one of the faces $1 \infty \infty$; this form occurs in *fluor* occasionally; it shows that it is not necessary that the members of a twin system should be exactly composed of *halves* of the forms from which they are derived. In fig. 501 the twin-plane is 111, the macle shows faces of both cube and octahedron, and occurs in *cuprite.* Fig. 502 is a common macle in *pyrites.*

Macled crystals may generally be recognised by their re-entering angles, but occasionally, as in fig. 503, there are no re-entering angles. This is a macle of the rhombic dodecahedron; the twin-plane, as before, is parallel to one of the planes 111, and the angle of revolution is 90°. Here, too, *c c* is the twin-axis, and *b b* the twin-plane.

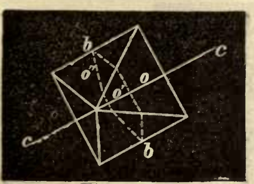


Fig. 498.

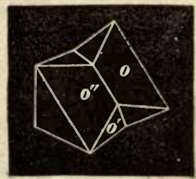


Fig. 499.

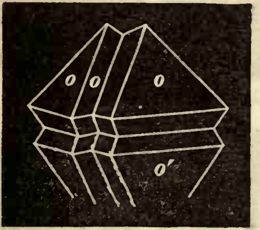
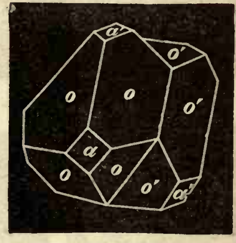


Fig. 500.



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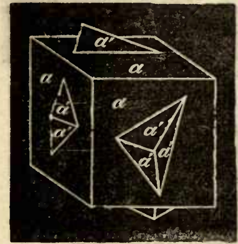

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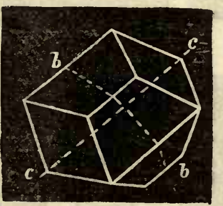

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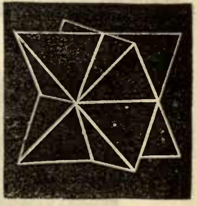

Fig. 504.

Figs. 504, 505, represent interpenetrating tetrahedrons of *fahlerz*, the twin-plane being 111.

131. Tetragonal Macles.—Examples are given in figs. 506 to 510 which occur in *cassiterite* and *rutile*. The last figure much resembles an hexagonal combination.

132. Rhombic Macles are given in figs. 511 to 521. A macle of *chalcocite* is given in fig. 511; *staurolite* in figs. 512, 513; *bournonite* in fig. 514; *cerussite* and *Aragonite* in figs. 515, 516, 517; *marcasite* in fig. 518; *wolfram* in fig. 519; *chrysoberyl* in fig. 520; *harmotome* in fig. 521.

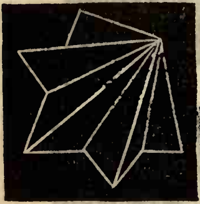

Fig. 505.

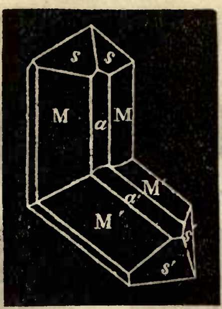

Fig. 506.

Fig. 507.

Fig. 508.

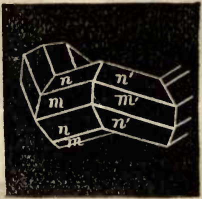

Fig. 509.

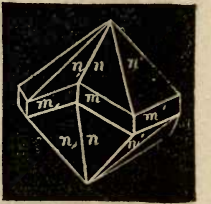

Fig. 510.

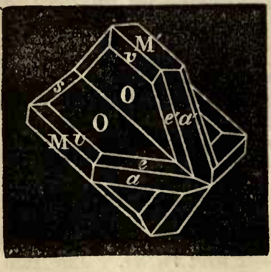

Fig. 511.

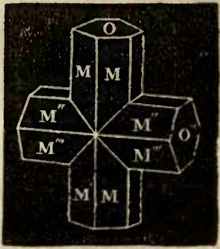

Fig. 512.

Fig. 513.

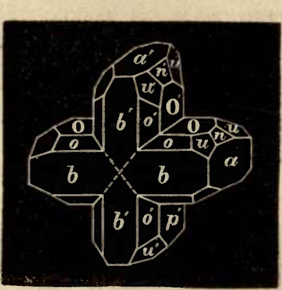

Fig. 514.

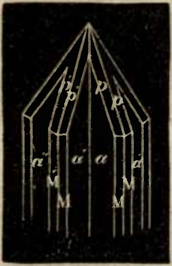

Fig. 515.

Fig. 516.

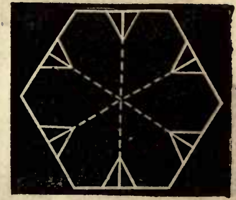

Fig. 517.

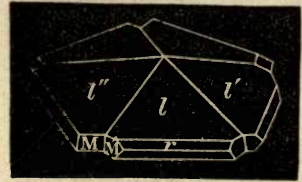

Fig. 518.

Fig. 519.

Fig. 520.

133. **Oblique Macles** are given in figs. 522 to 525, all of which occur in *orthoclase*. Fig. 525 is the same as fig. 524, seen from above.

134. **Anorthic Macles** occur frequently in *albite, oligoclase,* and *anorthite*. A macle of albite is given in fig. 526.

135. **Hexagonal Macles.**—These are very common, especially in *quartz* and *calcite*. Figs. 527, 528, are met with in

the former; fig. 529 is a very frequent macle in the latter. Many most beautiful hexagonal macles occur in snow crystals, eight of these forms are given in fig. 530.

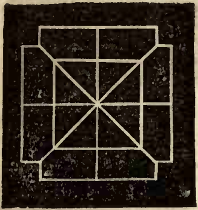

Fig. 521.

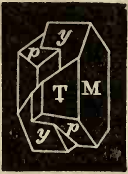

Fig. 522.

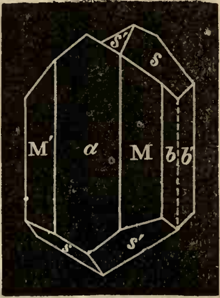

Fig. 523.

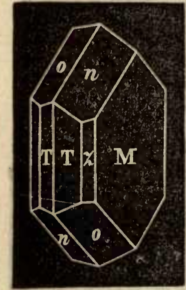

Fig. 524.

Fig. 525.

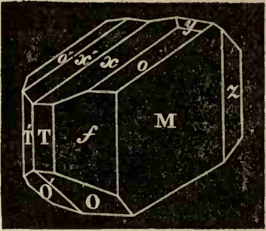

Fig. 526.

In macles composed of two members whose crystallographic axes are continuous with each other, so that the planes of one are continued without interruption into the other, we cannot always determine with certainty whether such combinations should be regarded as macles or not. Thus, in fig. 531, we may either treat the whole crystal as a combination of the prism and complete rhombohedron, or, viewing it as a twin, with a twin-plane *b b*, we may regard the upper planes as belonging to the *positive*, and the lower to the *negative* rhombohedron. In this case it is impossible to determine with certainty; but

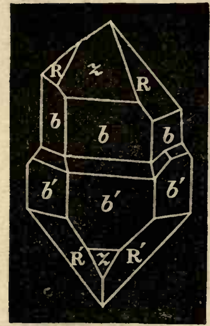

Fig. 527.

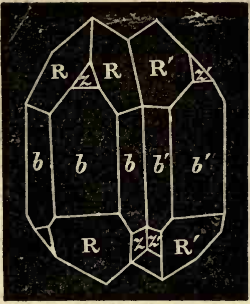

Fig. 528.

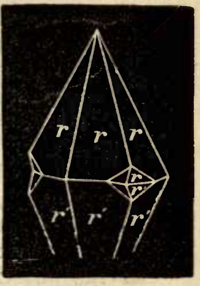

Fig. 529.

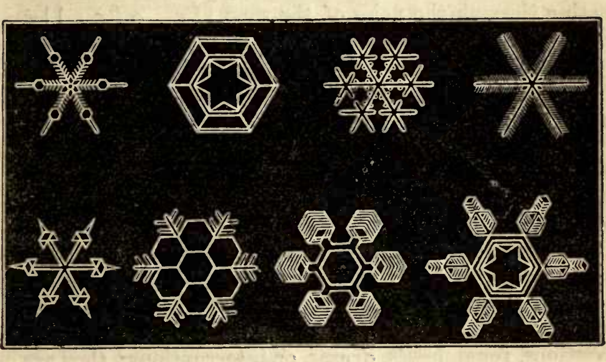

Fig. 530.

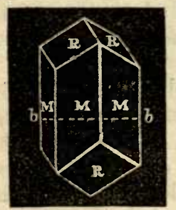

Fig. 531.

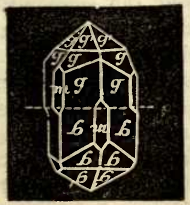

Fig. 532.

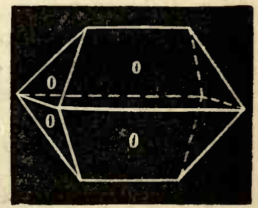

Fig. 533.

there are sometimes in such cases irregularities or partial modifications which enable us to determine the question with absolute certainty, such as the planes *m* in fig. 532, which is a macle of *pyrargyrite* figured by Dana.

136. Twin-planes.—In the cubical system the twin-plane is usually parallel to the plane 111, sometimes to $1\infty1$.

In the pyramidal system the chief twin-planes are parallel to the faces $1\infty\infty$, 11∞, $1\infty1$, $1\infty3$, 111, 113.

In the rhombic system the principal twin-planes are parallel to the planes 11∞, $\infty1\infty$, $1\infty\infty$, $1\infty1$, $1\infty\frac{3}{2}$, $1\infty2$, $1\infty\frac{2}{3}$, $\infty11$, $11\frac{1}{2}$, $1\frac{3}{2}\frac{3}{2}$.

In the oblique system the chief twin-planes are $1\infty\infty$ $\infty\infty1$, 31∞, $1\infty1$, $1\infty2$, $\infty11$, $\infty12$.

In the anorthic system the twin-planes are $\infty1\infty$ and $\infty\infty1$. There are also twin-planes perpendicular to a plane passing through the poles of the zone $\bar{1}1\infty$, $\infty1\infty$, 11∞, to those of the zone $\infty\infty1$, $1\infty1$, $1\infty2$; and of the zone $1\infty\infty$, 11∞, $\bar{1}1\infty$.

In the hexagonal system the chief twin-planes are parallel to $\infty\infty1$, 11∞, 121, $+R$, $+\frac{1}{4}R$, $-\frac{1}{2}R$, $-2R$.

Usually a movement through 90° would bring one member of a twin system into a position corresponding with that of the other, but in some instances a movement of 180° would be necessary.

137. Irregularities of Crystals.—These are very frequent, especially in the case of large crystals. We can only describe a few in this chapter. They may arise from the imperfect development of certain planes, the curvature of "planes," striations, roughnesses, druses, or interruptions; they are due probably to a want of room to crystallise, or a too free or too scanty supply of material, the aggregation of small crystals, etc. Certain combinations also give rise to deceptive forms which are often very difficult to detect.

138. Imperfect Development.—Examples are given in figs. 533 to 536. Figs. 533, 534, represent common forms in *alum;* fig. 535 is a crystal of *spinel,* described by the Comte de Bournon; fig. 536 is a crystal of *garnet* figured by Dana. Many other examples might be given. In all such instances of imperfect development, *i.e.*, of a greater

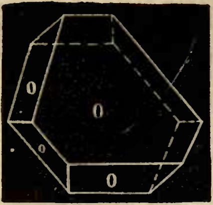

Fig. 534.

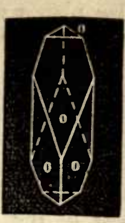

Fig. 535.

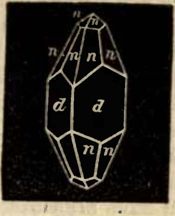

Fig. 536.

Fig. 537.

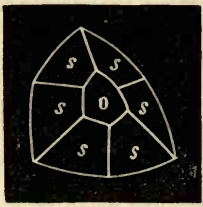

Fig. 538.

Fig. 539.

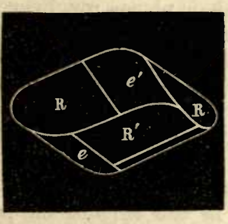

Fig. 540.

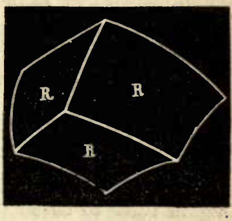

Fig. 541.

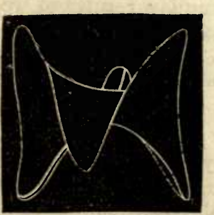

Fig. 542.

Fig. 543.

development of similar planes on some sides of the centre than on others, the *angles* made by the different planes (or their normals) with each other are unchanged. Thus, in figs. 533 and 534 the angles included between adjacent faces will be accurately those of a perfect octahedron, 70° 32′ between normals, or 109° 28′ between adjacent faces.

139. Curvature.—Examples are common in the *diamond*, *dolomite*, *chalybite*, and many other minerals. Figs. 537 to 539 have been observed in the first; figs. 540, 541, 542, in the second; fig. 543 in *cinnabar*; fig. 544 in *quartz*.

140. Striations, etc.—Frequently certain planes of crystals are seen to be *striated* in certain directions, as, for instance, the quartz crystals last figured. These striations may really be looked upon as a series of minute modifications or alternations of planes, as in the crystal of *beryl* from the United States, fig. 545. Fig. 544 would appear to owe its curvature to a similar series of alternations on a much smaller scale. Many crystals are rough on certain planes, and sometimes this roughness takes the form of a series of minute planes belonging to the same, or to a related crystal form. Thus, many octahedrons of *fluor* have their planes roughened with minute triangular or square planes, corresponding to the faces 111 and $1\infty\infty$, such crystals have been called *complex*, *compound*, or *polysynthetic*. Another kind of druse is when a crystal is sprinkled over on certain planes with minute separate crystals of the same or another mineral. This is really a coating deposited after the supporting crystal was fully formed, and the mineral is said to be *invested*. We shall again refer to these druses in the chapter on pseudomorphs.

We may here refer to the peculiar results of such alternations of form as are illustrated in figs. 546, 547. The first is a skeleton cube of *halite* or *rock-salt*, found sometimes in nature, it also occurs in *fluor*. The somewhat similar octahedron of *gold*, fig. 548, is also remarkable for the peculiar stalactitic formation of its lower portion.

141. Deceptive Forms.—Many of these have been already referred to and illustrated. Thus in the cubical system the tetrahedron and octahedron so closely resemble the pyramid 111 and the sphenoid $\frac{111}{2}$ of chalcopyrite, belonging to the pyramidal system, that they can only be distinguished by careful measurement. The irregularly developed octahedron, fig. 535, closely resembles an hexagonal form, while the rhombic dodecahedron and deltohedron, fig. 536, might easily be mistaken for a pyramidal combination, and the imperfectly developed crystal of alum, fig. 533, for a rhombic crystal. An irregularly developed rhombic dodecahedron, like fig. 548, is undistinguishable from an hexagonal prism with trihedral summits. Again, many combinations in the pyramidal system closely resemble others belonging to the rhombic system when the ortho- and brachy-diagonals happen to be nearly equal. The same may be said of anorthic forms, one of whose lateral axes happens to be nearly at right angles to another, and we have seen that the macle of *rutile*, fig. 510, exactly resembles an hexagonal combination.

Rhombic macles are often scarcely distinguishable from hexagonal prisms and pyramids, as in the cases of *Aragonite*, *cerussite*, *nitre*, etc., fig. 517. The macle of *harmotome*, fig. 521, exactly resembles a pyramidal prism. In all such cases, as we have already said in referring to the difficulty of

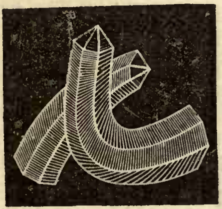
Fig. 544.

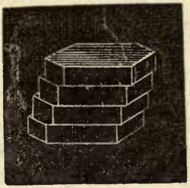
Fig. 545.

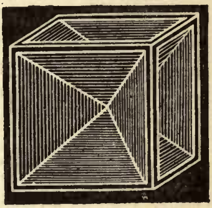
Fig. 546.

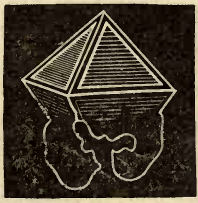
Fig. 547.

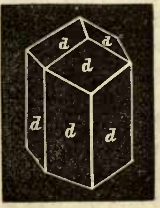

Fig. 548.

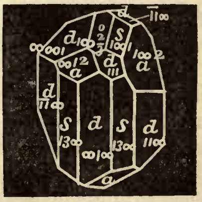

Fig. 549.

determining whether some macles of *calcite* are macles or not, search must be made for roughnesses, striations, variations of cleavage, slightly developed modifications, and the like, when a clue will generally be found leading to the true determinations.

142. Homology of different Systems.—As the position of any plane is accurately known when its intersections with three imaginary lines, called axes, all of which do not lie in one plane, are known, it would not be difficult to apply a system of three equal axes crossing each other at right angles to all crystal forms. Thus, supposing the respective lengths of the axes of the form 111 in the pyramidal system to be as 1 : 1 : 2, and those of a form 111 in the rhombic system to be as 1 : 2 : 3, then, still referring all planes to three axes, as in the cubical system, the symbols of the planes will be 112 and 123 respectively. The planes of the cube, tetragonal prism of second order, and of the prism on rectangular base in the rhombic system will be:

Cube,........................$1\infty\infty$, $\infty 1\infty$, $\bar{1}\infty\infty$, $\infty\bar{1}\infty$, $\infty\infty 1$, $\infty\infty\bar{1}$
Square prism,..............$1\infty\infty$, $\infty 1\infty$, $\bar{1}\infty\infty$, $\infty\bar{1}\infty$, $\infty\infty 2$, $\infty\infty\bar{2}$
Rectangular prism,......$2\infty\infty$, $\infty 1\infty$, $\bar{2}\infty\infty$, $\infty\bar{1}\infty$, $\infty\infty 3$, $\infty\infty\bar{3}$.

Similiar modifications might be arranged on this principle for all possible forms; but, of course, if the lengths of the axes did not happen to be in such simple ratios (and it is very seldom that the ratios are so simple), the symbols would be greatly encumbered by fractions. It will be observed that the parallelism of the symbols for the cube, with those for the rectangular prism (rhombic system), is less than with those for the square prism (tetragonal system). In the case of oblique, anorthic, and hexagonal crystals the parallelism of symbols would be still less, and there would be more difficulty in determining them, but it would evidently be quite possible to use such a universal system of axes.

We may here, however, call attention to the similarity which has been shown to exist, by Professor Dana, between certain cubical and oblique forms. Figs. 548, 549, will serve to illustrate his remarks. Fig. 548 is a rhombic dodecahedron, placed so that one of the trihedral angles is nearly at the summit or apex; and fig. 549 is a crystal of orthoclase. The planes of the rhombic dodecahedron are in each case marked *d*, but, in fig. 549, there are in addition three planes marked *a*, which correspond to the faces of the cube; three corresponding to the deltohedron 122, which truncate the edges of the rhombic dodecahedron, and finally, one of the planes of the octahedron appears in the figure marked *o*.

If a dodecahedron be so placed that an octahedral axis, *i.e.*, the line between the apices of two of the trihedral solid angles is vertical, it is then a six-sided prism with trihedral summits. If now this axis be inclined 8° 6′ (as in fig. 548), in one of the diametral planes of the six-sided prism, it will have the inclination of the axis of orthoclase (as in fig. 549), and this 8° 6′ is the greatest amount of divergence from the dodecahedral angles that occurs in the species. The planes *d d* are inclined to each other at angles near 120°, and as there are twelve in the crystal, they may be taken as their representatives although somewhat distorted.

The planes *s*, twelve in number, also have angles with each other near 150°, and they correspond with those of the deltohedron.

The planes *a* make angles with the planes *d* which are near 135°, the angle of the true cubical combination, and as they are six in number they may obviously be compared with the cubical faces.

Finally, the plane marked *o* is inclined very nearly 125° 16′ and 144° 44′ respectively to the cubic and dodecahedric faces, these being the correct angles for the true cubical combinations. These planes, therefore, may obviously be compared with the octahedral faces, but as they are only two in number, it is evident that six are suppressed.

The two cleavages in orthoclase are parallel to dodecahedric faces, and the twin-planes are either dodecahedric or cubic. Dana observes: "These relations hold true also for the triclinic felspars, the only peculiarity in which is that the principal section has slight lateral obliquity, so that the two (dodecahedric) cleavage planes incline to one another 93° 15′ instead of 90°"

143. **Dimorphism.**—Some mineral substances, such as carbonate of lime and sulphide of iron crystallise in two distinct forms, having different axes. Thus *calcite* and *Aragonite* are dimorphous forms of carbonate of lime, the first

crystallising in the hexagonal, the second in the rhombic system. In like manner sulphide of iron crystallises in the rhombic system in *marcasite*, and in the cubical system in *pyrites*. *Blende* (cubical), and *wurtzite* (rhombic); *senarmontite* (cubical), and *valentinite* (rhombic); and *barytocalcite* (oblique), and *bromlite* (rhombic), are additional examples of dimorphism. Some substances, as titanic oxide and silica, crystallise in three distinct forms, and are said to be trimorphous. Sulphide of silver affords another example of trimorphism as it crystallises in the cubical system in *argentite*, in the rhombic system in *daleminzite*, and again in the rhombic system, but with different parameters in *acanthite*. These different forms of crystallization in the same mineral substance are believed to indicate different conditions existing at the time of the formation of the substance—thus the temperature or pressure existing at the time of crystal lization of carbonate of lime may determine whether the resulting mineral shall be *calcite* or *Aragonite*.

144. Isomorphism.—When substances of different chemical composition crystallise in similar or nearly similar forms, they are said to be *isomorphous*, thus the carbonates of lime, iron, magnesia, and manganese are isomorphous, since they all crystallise in the hexagonal system, and the angles of their chief rhombohedrons do not differ from each other, except by a very few degrees. Moreover, it is found that these carbonates are rarely alone in natural mineral substances, a portion of the one carbonate being almost always "replaced" by one of the others. In any isomorphous group the similarity of form is generally accompanied by a similarity of other physical properties. In the cubical system isomorphism is, of course, very common, although not universal. The more important isomorphous or vicarious mineral substances (capable of replacing each other in atomic proportions without affecting the resulting form), may be arranged as follows:—

I. SIMPLE SUBSTANCES—
  a. Fluorine and chlorine, iodine, bromine.
  b. Sulphur and selenium.
  c. Arsenic, antimony, tellurium, bismuth.
  d. Cobalt, iron, nickel.
  e. Copper, silver, mercury, gold.

II.—A. OXIDES—Formula, $\overset{\cdot}{R}O$ or $\overset{\cdot}{R}$—
a. Lime, magnesia, protoxide of iron, protoxide of manganese, oxide of zinc, oxide of nickel, oxide of cobalt, potash, soda, yttria, oxide of cadmium, oxide of cerium.
b. Lime, baryta, strontia, oxide of lead.
B. OXIDES—Formula, R_2O or $\overset{\cdot}{R}_2$—
a. Sub-oxide of copper, sub-oxide of lead.
C. OXIDES—Formula, R_2O_3 or $\overset{\cdot\cdot\cdot}{R}_2$—
a. Alumina, peroxide of iron, peroxide of manganese, oxide of chromium, oxide of bismuth.
b. Oxide of antimony, arsenious acid.
D. OXIDES—Formula, $RO_2 = \overset{\cdot\cdot}{R}$—
a. Oxide of tin, oxide of titanium.
E. OXIDES—Formula, $R_2O_5 = \overset{\cdot\cdot\cdot\cdot\cdot}{R}_2$—
a. Phosphoric acid, arsenic acid.
F. OXIDES—Formula, $RO_3 = \overset{\cdot\cdot\cdot}{R}$—
a. Sulphuric acid, selenic acid, chromic acid, manganic acid.
b. Tungstic acid, molybdic acid.

III.—A. SULPHIDES—Formula, $RS_2 = R''$—
a. Sulphide of iron, sulphide of zinc.
B. SULPHIDES—Formula, $RS = R'$—
a. Sulphide of copper, sulphide of silver.
C. SULPHIDES—Formula, $R_2S_3 = R_2'''$—
a. Sulphide of antimony, sulphide of arsenic.

145. Polymerous Isomorphism.—Scheerer states that in compounds containing magnesia, protoxide of iron, and the other oxides mentioned (II. A *a*) above, part of the base may be replaced by water, in the proportion of three equivalents of water for each equivalent of base replaced. Thus, $3MgO, SiO_2$, $2MgO, SiO_2 + 3H_2O$, and $MgO, SiO_2 + 6H_2O$ are isomorphous compounds, the first being *chrysolite*, the last *serpentine.* This theory has been adversely criticised by Haidinger, Naumann, and Rammelsberg, and, on the whole, seems still to need confirmation from facts.

146. Aggregates.—Crystals and crystalline grains of the same or different minerals are often intermixed regularly or irregularly together in great quantities to form rock-masses. These are called mineral aggregates. The most important are the *granular* or *granitic*, *porphyritic*, *oolitic*, *saccharoid*, and *foliated* aggregates. The study of these belongs to Petrology.

CHAPTER XVII.

OF DIMORPHISM, PSEUDOMORPHISM, AND PETRIFACTION.

147. Pseudomorphism.—In the last chapter we have described certain "deceptive forms," which, while apparently belonging to one system of crystallization, really belong to another. We have now to describe certain bodies, called Pseudomorphs, the results of processes of change which are constantly going on in nature, and which occur in forms different from those properly belonging to the substances in question.

148. Hypostatic* Pseudomorphs.—These are formed by the deposition of mineral matter upon the surface of pre-existing minerals. When the new matter is deposited only on the exterior, as in the case of the "druses" already referred to, the term *exogene*† is used; when upon the interior of a hollow mineral the term *esogene*‡ is applied; and if in both the term *amphigene*.§ Exogene pseudomorphs often retain the original mineral within them, partly or completely filling up the interior; but sometimes they are mere hollow shells, empty, or filled with water, or with mineral solutions. Sometimes these hollow shells have been subsequently filled with new mineral substance, and still later the shell itself has been removed, when the final result is a new body having precisely the form of the original. All these different stages have been observed, for example, in pseudomorphs of *quartz*, after *fluor*, in the Gwennap Mines; *chalybite*, after gypsum, at Virtuous Lady Mine.

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* ὕποστατος (*hypostatos*), to be sustained.

† εξ (*ex*), without; and γινομαι (*ginomai*), I am born.

‡ ες (*es*), within; and γινομαι.

§ αμφι (*amphi*), both; and γινομαι.

149. Metasomatic Pseudomorphs.[*]—In these, which are the most common, as well as the most important, pseudomorphs, some only of the elements present have been usually changed by removal or substitution. The original crystal appears to have been surrounded, by causes which we need not now study, by media, such as air, water, hydrofluoric acid, etc., capable of affecting its decomposition, slowly or rapidly as the case may be. This medium has removed some of the ingredients or components, and has sometimes given up some of its own at the same time, which remain behind to form part of the new substance. If these changes are slow they may not affect the original form of the substance acted on. This kind of pseudomorphous action has often taken place on a very large scale; thus there is good reason to believe that over large tracts of country the felspar, forming a constituent part of masses of granitic rocks, has been completely kaolinised by hydrofluoric acid acting from below, and large veins of carbonate of iron have been converted into limonite or hematite by the action of the air or of surface waters.

When the result has been the formation of a more highly oxidised or electro-negative substance, as in the case of chalybite or iron pyrites converted into hematite, the new bodies are called *anogene*[†] pseudomorphs; when the change is in the opposite direction, as of felspar into kaolin, or rock-salt into gypsum, they are called *katogene*[‡] pseudomorphs.

150. Petrifactions.—These also are processes of pseudomorphism of several kinds. The most general is that in which a thin layer of mineral matter is deposited upon an organic substance so as to preserve its external form, as in the cases of the so-called petrifying springs of Matlock and elsewhere.

If now the organic substance forming the interior of such a petrifaction should be removed by solution, or should shrink and fall to powder from decay, and the cavity be filled up anew with mineral matter, and finally the original coating be removed, a cast having the form of the original substance would be left. Of this nature are the sandstone tree-stems

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[*] μετα (*meta*), together with (used sometimes in the sense of transposition); and σωμα (*soma*), a body or substance.

[†] ανα (*ana*), upwards.

[‡] κατα (*kata*), downwards.

which occur so abundantly in the coal measures, and the pyritous casts of ammonites found in the gault.

The above are analagous to the hypostatic pseudomorphs already described; but there is a more perfect kind of petrifaction analagous to the metasomatic pseudomorphs. This results from the infiltration of mineral matter, usually carbonate of lime or silica, into and between the cells of organic substances before decay has set in. In such cases the minutest details of structure are sometimes preserved, and the character of a fossil wood may be readily determined after it is completely silicified. Most fossils have been petrified by one or other of the methods above described.

The following list of pseudomorphs, which, however, is far from complete, will be useful for reference:—

HYPOSTATIC PSEUDOMORPHS.

Graphite	*in the form of*	Pyrites.
Salt	,,	Magnesite.
Anhydrite	,,	Salt.
Gypsum	,,	Salt, Cerussite.
Polyhalite	,,	Salt.
Quartz	,,	Fluor, Gypsum, Calcite, Barytocalcite, Magnesite, Scheelite, Galena, Cerussite, Hematite, Pyrites, Chalybite, Felspar, Copper.
Prase	,,	Calcite.
Eisenkiesel	,,	Calcite.
Chalcedony	,,	Barytes, Fluor, Calcite, Magnesite, Pyromorphite.
Carnelian	,,	Calcite.
Hornstone	,,	Fluor, Calcite, Mica, Chalybite.
Semiopal	,,	Calcite.
Lithomarge	,,	Fluor.
Pyrites	,,	Quartz, Stephanite, Pyrargyrite.
Marcasite	,,	Pyrargyrite.
Chalybite	,,	Barytes, Calcite, Magnesite, Selenite, Fluor.
Malachite	,,	Calcite, Cerussite.
Chrysocolla	,,	Cerussite.
Felspar	,,	Calcite.
Meerschaum	,,	Calcite.
Pyrolusite	,,	Calcite, Magnesite.
Hausmannite	,,	Calcite.
Manganite	,,	Calcite.
Psilomelane	,,	Barytes, Fluor, Pharmacosiderite.

Smithsonite	*in the form of*	Fluor, Calcite, Magnesite, Galena, Pyromorphite.
Cassiterite	,,	Pyromorphite, Felspar, Bismuthinite.
Cerussite	,,	Barytes, Fluor.
Stilpnosiderite	,,	Magnesite, Calamine.
Hematite	,,	Fluor, Calcite, Chalybite, Cinnabar.
Limonite	,,	Barytes, Fluor, Calcite, Magnesite, Quartz, Comptonite, Blende, Galena, Pyromorphite, Cerussite, Cuprite.
Pyrites,	,,	Barytes, Calcite, Chalcocite.
Marcasite	,,	Fluor, Calcite.
Calcite	,,	Limonite.
Barytes	,,	Chalybite.
Celestite	,,	Blende.
Fluor	,,	Galena.
Opal	,,	Chalcopyrite.
Talc	,,	Erubescite.

PSEUDOMORPHS AFTER ORGANIC FORMS.

(*Petrifactions.*)

Pyrites	*in the form of*	Ammonites, Shells, Wood, etc.
Opal	,,	Wood.
Chalcedony	,,	Animal forms (Beekites).
Barytes	,,	Animal forms.
Flint	,,	Sponges, Shells, etc.

METASOMATIC PSEUDOMORPHS.

a. By Loss of Components.

Calcite	*in the form of*	Gaylussite.
Quartz	,,	Heulandite, Stilbite.
Kyanite	,,	Andalusite.
Steatite	,,	Hornblende.
Copper	,,	Cuprite.
Argentite	,,	Pyrargyrite.

b. By Addition of Components.

Gypsum	*in the form of*	Anhydrite.
Mica	,,	Pinite.
Valentinite	,,	Antimonite.
Anglesite	,,	Galena.
Hematite	,,	Magnetite.
Limonite	,,	Hematite.
Malachite	,,	Cuprite.
Erubescite	,,	Chalcocite.
Chalcopyrite	,,	Chalcocite.

c. By Exchange of Components.

Barytes	*in the form of*	Witherite and Barytocalcite.
Fluor	,,	Calcite.
Gypsum	,,	Calcite.
Calcite	,,	Gypsum.
Magnesite	,,	Calcite.
Chalcedony	,,	Datholite.
Jasper	,,	Hornblende.
Opal	,,	Augite.
Cimolite	,,	Augite.
Lithomarge	,,	Topaz, Felspar, Nepheline.
Kaolin	,,	Felspar, Porzellanspath, Leucite.
Mica	,,	Andalusite, Felspar, Scapolite, Tourmaline, Cordierite.
Hard Fahlunite	,,	Cordierite.
Aspasiolite	,,	Cordierite.
Fahlunite	,,	Cordierite.
Esmarkite	,,	Cordierite.
Bonsdorffite	,,	Cordierite.
Chlorophyllite	,,	Cordierite.
Weissite	,,	Cordierite.
Praseolite	,,	Cordierite.
Pyrargillite	,,	Cordierite.
Gigantolite	,,	Cordierite.
Pinite	,,	Cordierite.
Prehnite	,,	Analcime, Mesotype, Leonhardite.
Talc	,,	Chiastolite, Kyanite, Couzeranite, Felspar (?) Pyrope.
Steatite	,,	Magnesite, Spinel, Quartz, Andalusite, Chiastolite, Topaz, Felspar, Mica, Scapolite, Tourmaline, Staurolite, Garnet, Idocrase, Augite.
Serpentine	,,	Spinel, Mica, Garnet, Augite, Chondrodite, Hornblende, Olivine.
Hornblende	,,	Augite.
Chlorite	,,	Felspar, Garnet, Hornblende.
Pyrolusite	,,	Manganite.
Hausmannite	,,	Manganite.
Valentinite	,,	Antimonite.
Stibiconite	,,	Antimonite.
Kermes	,,	Antimonite.
Bismuthochre	,,	Aikinite.
Minium	,,	Galena, Cerussite.
Galena	,,	Pyromorphite.
Pyromorphite	,,	Galena, Cerussite.
Cerussite	,,	Galena, Anglesite, Leadhillite.
Wulfenite	,,	Galena.
Magnetite	,,	Chalybite.
Hematite	,,	Göthite, Pyrites, Pharmacosiderite.

Limonite	*in the form of*	Chalybite.
Stilpnosiderite	,,	Marcasite, Scorodite.
Pyrites	,,	Vivianite.
Melanterite	,,	Mispickel.
Green Earth	,,	Pyrites.
Pseudotriplite	,,	Augite.
Wolfram	,,	Triphylline.
Erythrite	,,	Scheelite.
Melaconite	,,	Smaltite.
Pitchy Copper Ore	,,	Chalcocite.
Covellite	,,	Chalcopyrite, Fahlerz.
Malachite	,,	Chalcopyrite.
Chessylite	,,	Chalcopyrite, Fahlerz.

CHAPTER XVIII.

ON MEASURING CRYSTALS.

151. Constancy of Angles.—Generally, whatever the apparent irregularity of single crystals or combinations of forms, the angles made with each other by similar planes are constant within very narrow limits. It is only by measuring these angles that numerical values can be assigned as the indices of the different planes, and sometimes the *system* of crystallization can only be determined by such measurements. To measure these angles *goniometers* are used, which are of two different kinds, the one measuring the angle directly by contact, the other indirectly by reflexion.

152. Carangeot's Goniometer.—This is a contact goniometer; it consists of a small semicircle divided into degrees, and a pair of movable arms of brass jointed at their intersection. In using this instrument the movable arms are applied to the crystal, as shown in fig. 550, until the two arms rest accurately upon the planes in a direction at *right angles* to the included *edge*. The screw at the intersection is then tightened, and the arms are applied to the brass semicircle, as shown in fig. 551, when the number of degrees of inclination may be at once read off.

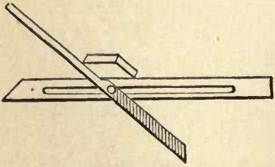

Fig. 550.

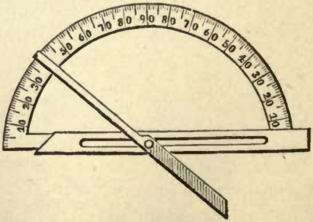

Fig. 551.

This mode of measurement is sufficient for the beginner, but it is difficult to get results within a degree or so, and it is not applicable to very small crystals, nor to the re-entering angles of macles.*

153. Wollaston's Goniometer.—In this instrument the crystal is attached to a graduated circle which is made to revolve so that the image of a window bar, or other object seen by reflexion from one of its surfaces, is brought to coincide with the image of a second signal seen directly in the next face. The following description of the principle of the instrument, and of the mode of using it is, with the accompanying figures, taken from Mr. Brooke's description in the *Encyclopædia Metropolitana*:—

"This purpose is effected by causing an object, as the line at *m* (fig. 552), to be reflected successively from the two planes, *a* and *b*, at the same angle. It is well known that the images of objects are reflected from bright planes at the same angle as that at which their rays fall on those planes; and that when the image of any object reflected from a horizontal plane is observed, it appears so much below the reflecting surface as the object itself is above.

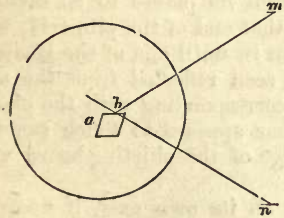

Fig. 552.

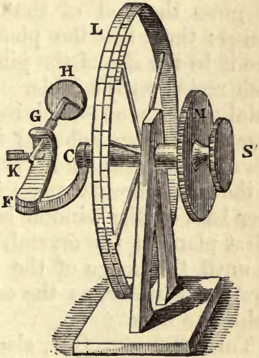

Fig. 553.

"If, therefore, the planes *a* and *b* (fig. 552) are successively brought into such positions as will cause the reflexion of the line *m* from each plane to appear to coincide with another line at *n*," the crystal must have been revolved through as

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* A convenient mode of measuring re-entering angles is to take a cast of them in wax.

many degrees as the angle included by the planes *ab*. "To bring the planes of any crystal successively into these relative positions the following directions will be found useful:—

"The instrument, as shown in the sketch (fig. 553), should be first placed on a pyramidal stand, and the stand on a small steady table about 6 to 10 or 12 feet from a flat window. The graduated circular plate should stand perpendicularly from the window, the pin GH being horizontal, not in the direction of the axis, as is usually figured, but with the slit end nearest the eye.

"Place the crystal which is to be measured on the table, resting on one of the two planes whose inclination is required, and with the edge at which those planes meet nearest and parallel to the window. Attach a portion of wax, about the size of *d*, to one side of a small brass plate, *e* (fig. 554); lay the plate on the table with the edge, *f*, parallel to the window, the side to which the wax is attached being uppermost, and press the end of the wax against the crystal till it adheres; then lift the plate with its attached crystal and place it in the slit of the pin, GH, with that side uppermost which rested on the table. Bring the eye now so near the crystal as, without perceiving the crystal itself, to permit the images of objects reflected from its planes to be distinctly observed, and raise or lower that end of the pin, GH, which has the small circular plate on it, until one of the horizontal upper bars of the window is seen reflected from the upper or first plane of the crystal, corresponding with the plane *a*, and until the image of the bar appears to touch some line below the window, as the edge of the skirting-board where it joins the floor.

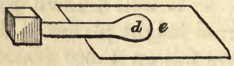

Fig. 554.

"Turn the pin, GH, also on its own axis, if necessary, until the reflected image of the bar of the window coincides accurately with the observed line below the window. Turn now the small circular handle, S, on its axis, until the same bar of the window appears reflected from the second plane of the crystal, until it appears to touch the line below; and having, in adjusting the *first* plane, turned the pin, GH, *on its axis*, to bring the reflected image of the bar of the window to coincide accurately with the line below, *now move the lower end of the pin laterally*, either towards or from the instrument, in order to make the image of the same bar, reflected from the second plane, coincide with the same line below. Having ascertained, by repeatedly looking at and adjusting both planes, that the image of the horizontal bar, reflected successively from each plane, coincides with the observed lower line, the crystal may be considered ready for measurement.

"The accuracy of the measurements taken with this instrument will depend upon the precision with which the image of the bar, reflected successively from both planes, is made to appear to coincide with the same line below; and also upon the 0 or 180° of the graduated circle, being made to stand precisely even with the lower line of the vernier, when the first plane of the crystal is adjusted for measurement. A wire being placed horizontally between two upper bars of the window, and a black line of the same thickness being drawn parallel to it below the window, will contribute to the exactness of the measurement by being used instead of the bar of the window and any other line.

"Persons beginning to use this instrument are recommended to apply it first to the measurement of fragments at least as large as that represented in fig. 554, and of some substance whose planes are bright. Crystals of carbonate of lime will supply good fragments for this purpose, if they are merely broken by a slight blow of a small hammer.

"For accurate measurement, however, the fragments ought not, when the planes are bright, to exceed the size of that shown in fig. 553, and they ought to be so placed on the instrument, that a line passing through its axis should pass also through the centre of the small minute fragment which is to be measured. This position on the instrument ought also to be attended to when the fragments of crystals are large. In which case the common edge of the two planes, whose inclination is required, should be brought very nearly to coincide with the axis of the goniometer; and it is frequently useful to blacken the whole of the planes to be measured, except a narrow stripe on each, close to the edge over which the measurement is to be taken."

Prof. Naumann has invented a modification of that part of the instrument used for adjusting the crystal to be measured, which is shown in fig. 555. He also adds a small mirror on the stand below the crystal with its face parallel to the axis *aa*, and inclined 45° to the window, when the lower signal can be dispensed with.

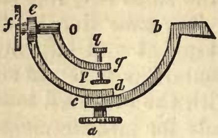

Fig. 555.

The student will often find it sufficient to attach the crystal by a piece of wax to the axis *a* directly, and give it the further adjustment by the hand. The only use of the parts C to H is to enable the observer to place the crystal accurately, *i.e.*, with the intersection of the planes to be measured parallel to, and as nearly as possible coinciding with, the centre of the axis. This is effected when the reflexion of the horizontal signal in both faces appears to be parallel to the included edge.*

154. O'Reilly's Goniometer.—The goniometer just described is extremely accurate, in good hands giving results whose errors are less than the variations of the crystals themselves. It is not however sufficiently portable for field use. Prof. O'Reilly has recently invented a reflecting goniometer which is little larger than a carpenter's pencil, and which gives exceedingly good results. To economise space the graduation is made to wind in a spiral around a thin cylinder, and the crystal is attached by wax directly to the principal axis of the instrument.†

155. Reading Crystals.—The student should at first practice on models belonging to the cubical system, commencing with simple holohedral forms, then proceeding to hemihedral forms and combinations. He should then compare the simple forms of the other systems with those of the cubical system, and gradually pass on to forms of greater complexity. He should also accustom himself to observe and sketch small natural crystals.

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* An easily constructed form of reflecting goniometer, devised by Mr. J. B. Hannay of Glasgow, is described and illustrated in the *Mineralogical Magazine* for April 1877.

† The instrument is fully described and illustrated in the *Proceedings of the Royal Irish Academy*, Vol. I., Sec. xi., No. 5.

In order to read forms with advantage, he should endeavour to place the crystals or models on any convenient stand, so that one axis, the principal if there is one, is vertical, and another facing him directly right and left. By looking down from above on a crystal so placed, he will have it placed as in Miller's figures belonging to the tetragonal, rhombic, and hexagonal systems. When there is a distinct cleavage he will, if the species is known, get a good indication of the planes, as the cleavages are always parallel to certain planes.

156. Useful Rules.—The following simple rules will be useful to the young student in making out crystal forms.

Two pairs of planes, forming angles of 90° with each other, may occur in all the systems except the *anorthic;* three pairs forming such angles with each other are only likely to occur in the *cubical*, *pyramidal*, and *rhombic* systems.

Angles of 60° and 120° occur more often in the *cubical* and *hexagonal* systems than in any of the others.

Angles of 109° 28′, 70° 32′, and 135° are almost characteristic of the cubical system.

Zones should be recognised as soon as possible, as they will greatly assist the determinations of the less characteristic planes. Any one plane may, of course, be common to two or more zones.

For any plane *d* of a zone *ada*, fig. 556, the sum of the angles between *d* and the two adjoining planes *aa* equals 180° + the inclination of *a* upon *a*. In the case represented in the figure the angles are—

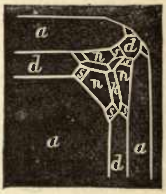

Fig. 556.

$$a \wedge d = 135^\circ$$
$$d \wedge a = 135^\circ$$
$$\text{Sum} = 270^\circ = 180^\circ + 90^\circ,$$
which latter is the inclination of $a \wedge a$.

The angles between normals to the extreme planes of any series, forming not more than half a complete zone, will equal the sum of the angles made by the normals to the different faces.

CHAPTER XIX.

PHYSICAL PROPERTIES—CLEAVAGE.

157. The crystalline form of such minerals as occur in distinct crystals is a character of much importance, but perfect crystals are generally rare, and many important minerals do not crystallise at all. The study of the other physical characters of minerals becomes therefore of the highest importance to all students of mineralogy.

The chief physical characters of minerals, excluding *form*, which has been dealt with in great detail, and the optical and chemical characters to be described hereafter, may be arranged under the following heads:—

CLEAVAGE.
STRUCTURE.
FRACTURE.
FRANGIBILITY (tenacity).
HARDNESS.
TOUCH.
SPECIFIC GRAVITY.
MAGNETISM.
ELECTRICITY.

CLEAVAGE.—This is the property possessed by many *crystallised* and *crystalline* minerals, of splitting in certain directions more readily than in others; affording shining surfaces, sometimes *curved*, but usually *plane*, called *cleavage planes*. These cleavages are spoken of as *perfect* when very smooth, *less perfect* or imperfect when the new surfaces are somewhat irregular. Sometimes cleavages are spoken of as *highly perfect*, *very perfect*, *perfect*, *imperfect*, and *very imperfect*. Thus, *calcite* has a highly perfect and *quartz* a very imperfect cleavage.

The cleavages are usually parallel to the faces of one of the simpler "forms," consequently, as already mentioned, they render great assistance to the crystallographer by giving him certain fixed points to start from in "reading" a crystal.

The student should obtain specimens of such easily cleavable minerals as galena, fluor, blende, calcite, etc., and endeavour to obtain from them the different cleavage forms. Thus, from fluor he may get the octohedron and acute rhombohedron, from galena the perfect cube, from blende the rhombic dodecahedron, and from calcite the rhombohedron. By laying the mineral upon a thin cushion or leather pad, placing the edge of a stout knife so as to coincide in direction with the plane of cleavage, and striking the back of the knife sharply with a light hammer, very good cleavage forms may be got without injuring the surfaces already existing.

The following minerals have perfect, and, mostly, easy cleavages, parallel to the planes indicated :—

Cubical System.

1∞∞

Alabandite.
Cobaltite.
Cubane.
Gahnite.
Galena.
Gersdorffite.
Hauerite.
Magnetite.
Naumannite.
Periclase.
Salt.
Skutterudite.
Sylvine.
Ullmanite.

111
Diamond.
Fluor.

11∞
Blende.
Hauerite.
Haüynite.

Pyramidal System.

1∞∞.
Scapolite.

1∞∞.
Idocrase.

1∞1.
Anatase.
Braunite.

1∞2.
Torbernite.

∞∞1.
Anatase.
Apophyllite.
Hausmannite.
Nagyagite.
Somervillite.
Torbernite.
Autunite.

Rhombic System.

∞∞1.

Anhydrite.
Barytes.
Celestite.
Cryolite.
Dyscrasite.
Eudnophite.
Fayalite.
Leadhillite.
Loganite.
Prehnite.
Roselite.
Sternbergite.
Thenardite.
Topaz.
Tyrolite.

∞1∞.
Anhydrite.
Jamesonite.
Niobite.
Pyrolusite.
Struvite.
Wolfram.

1∞∞.

Anhydrite.
Antimonite.
Aragonite.
Atacamite.
Brochantite.
Comptonite.
Diaspore.
Epistilbite.
Epsomite.
Göthite.
Haidingerite.
Harmotome.
Manganite.
Mascagnite.
Niobite.
Olivine.
Orpiment.
Phillipsite.
Picrosmine.
Polianite.
Pyrclusite.
Staurolite.
Stilbite.
Wavellite.
Wolfram.
Wolfsbergite.

11∞.

Barytes.
Loganite.
Manganite.
Mendipite.
Mesotype.
Pyrolusite.
Smithsonite.
Strontianite.
Valentinite.
Wavellite.
Witherite.

Oblique System.

∞∞1.

Orthoclase.
Glauberite.
Klinoclase.
Lepidolite.
Malachite.
Melanterite.
Mica.
Mirabilite.
Monazite.
Realgar.
Rhyacolite.
Triphylite.

1∞∞.

Epidote.
Hypersthene.
Linarite.
Spodumene.
Tincal.

∞1∞.

Annabergite.
Brewsterite.
Erythrite.
Euclase.
Gypsum.
Heulandite.
Köttigite.
Laumonite.
Malachite.
Pharmacolite.
Symplesite.
Vivianite.

11∞.

Achmite.
Amphibole.
Arfvedsonite.
Augite.
Botryogen.
Gaylussite.
Lehmannite.
Scolezite.

Anorthic System.

∞∞1.

Albite.
Babingtonite.
Christianite.
Labradorite.
Oligoclase.
Sassolite.

∞12.

Chessylite.

∞1∞.

Christianite.

HEXAGONAL SYSTEM.

$\infty\infty 1$.

Antimony.
Arsenic.
Biotite.
Bismuth.
Brucite.
Clintonite.
Chlorite.
Corundum.
Cronstedtite.
Covellite.
Eudialyte.
Hydrargillite
Parisite.
Pyrosmalite.
Pyrrhotite.
Ripidolite.
Spartalite.
Stilpnomelane.
Susannite.
Chalcophyllite.
Telluric Bismuth.
Tetradymite.
Willemite.

$\frac{111}{2}=R$.

Ankerite.
Calcite.
Chabasite.
Chalybite.
Corundum.
Diallogite.
Dolomite.
Magnesite.
Mesitite.
Millerite.
Nitratite.
Pyrargyrite.
Tourmaline.
Willemite.
Xanthoconite.

12∞.

Spartalite.

11∞.

Cinnabar.
Tellurium.

$-\frac{111}{2}=-R$.

Millerite.

$\frac{1}{2}R$.

Dioptase.
Millerite.

158. **False Cleavages.**—These are sometimes, and more properly, called *planes of union.* They are formed when two or more crystals increase so as to come in contact. In such cases there is a sort of adhesion; but the compound mass breaks more readily between the crystals than elsewhere. As the broken surfaces so produced are often smooth and shining, they may be mistaken for true cleavages. They may however be easily distinguished, since with a true cleavage other lamellæ may be readily split off parallel to the first one produced; but this is not so with false cleavages.

The cleavage of rocks is frequently quite a distinct phenomena to that of minerals; but sometimes it is determined by the prevailing directions of the constituent minerals. Thus in mica schist the plates of mica have usually a prevailing direction, parallel to which the rock splits readily. In like manner, in many kinds of granite, the felspar crystals have a prevailing direction, which determines the "cleavage" of the mass.

CHAPTER XX.

PHYSICAL PROPERTIES—STRUCTURE, ETC.

159. Structure.—Properly speaking, the *cleavage* of crystals is part of their *structure*, but it is more convenient to treat the other kinds of structure separately. The chief varieties of structure, as distinct from cleavage, are called—

a. Fibrous.—Made up of thin, straight, or curved fibres lying side by side. They have often a silky lustre. *Satin spar* is a name given to fibrous varieties of *gypsum* and *aragonite*, in which this silky lustre is very strongly marked.

b. Reticulate.—The same as fibrous, but the fibres crossing each other irregularly in all directions, as in the mineral called *mountain leather*.

c. Stellate.—The fibres radiating from centres in all directions, as in *stilbite* and some varieties of *gypsum*.

d. Radiate or *Divergent.*—The fibres diverging from each other, but not producing complete stars, as in *antimonite* and *pyrolusite*.

e. Lamellar.—The mineral appearing to consist of flattened leaves or laminæ, as in *bronzite*. The laminæ may be either flat or curved.

f. Foliaceous or *Micaceous.*—The leaves being very thin, as in *mica* and *selenite*.

g. Granular.—Apparently made up of minute grains, as in *chalk* or *kaolin*.

160. Fracture.—Any broken surface other than a *cleavage plane*, or *plane* of union, of two or more crystals.

According to its general form it may be—

a. Conchoidal (shell-like).—Having curved markings like those seen on the inside of many bivalve shells, as in *flint* and *opal*.

b. Even.—A surface free from marked depressions or elevations, as in *chalcocite*.

c. Uneven.—A surface having irregular depressions or elevations, as in *cassiterite.*

According to the nature of the broken surface the fracture may be—

d. Smooth, as in *lithomarge.*

e. Splintery, as in *serpentine.*

f. Earthy, as in *kaolin.*

g. Hackly, or covered with sharp wire-like points, as in *native copper.*

161. Frangibility or Tenacity.—Minerals may be—

a. Tough, or only broken with difficulty, as *hornblende.*

b. Brittle.—Parts of the mineral fly off in powder on attempting to cut or scratch it. Very easily broken with a blow, as *tourmaline* (schorl).

c. Sectile.—Thin pieces may be cut off with a knife, but the mineral falls to powder by hammering, as *chalcocite.*

d. Malleable.—When slices may be cut off and flattened under the hammer, as *native copper.*

e. Friable or *Pulverulent.*—The mineral is easily crushed between the fingers to a powder.

f. Elastic.—The mineral may be bent, but springs back to its former position when the bending force is removed. Example, *mica.*

g. Flexible, the mineral may be bent, and remains so after the bending force is removed. Example, *molybdenite.*

162. Touch.—A property of some importance in the discrimination of minerals. Thus, some minerals feel *unctuous,* like *graphite* and *talc;* others feel *harsh,* like *actinolite;* others, again, feel *meagre,* like *magnesite.*

163. Hardness.—This is a character of much importance in the discrimination of minerals. It is usually expressed by comparison with the following "Scale of Hardness:"—

1. TALC.
2. GYPSUM (or Rock-Salt).
3. CALCITE.
4. FLUOR.
5. APATITE.
6. ORTHOCLASE.
7. QUARTZ.
8. TOPAZ.
9. CORUNDUM.
10. DIAMOND.

The hardness of a mineral may be determined in different ways:—

1. By attempting to scratch it with the minerals in the foregoing list successively.

2. By passing a finely cut file over the specimens, with a rather firm pressure, three or four times.

3. By attempting to scratch the specimen with a knife.

Several trials should be made to obtain certain results, and each method should be tried if possible. Thus, suppose the specimen is a piece of *chalcocite.* No. 2 (*gypsum*) fails to scratch it, but No. 3 (*calcite*) scratches its surface readily. Next, reversing the method, it is found that the specimen under trial will scratch No. 2 readily, but not No. 3. On trying it with the file it is not rubbed away so readily as No. 2, but more readily than No. 3. It would be sufficient to set down its hardness at 2·5.

164. Easy as this method may seem, some precautions are, nevertheless, necessary. Thus, in a fibrous specimen, a scratch directed *across* the fibres will always indicate a lower degree of hardness than the true one, the scratch should therefore be parallel to the fibres, or still better, on the surface of a transverse fracture.

A sound, undecomposed specimen should always be selected, since the hardness of minerals is greatly affected by decomposition. Many minerals are *softer* when first obtained, than after they have been kept some time in a dry cabinet. In crystals, the edges and angles are often considerably harder than the faces, and those of the primitive form than of the modifications. The portion of the specimen selected for trial should be, as nearly as possible, of the same shape as that of the comparative specimens.

165. Brittleness should not be mistaken for hardness. Many minerals which are too hard to be scratched, are yet forced away in powder before the knife to some extent.

Some minerals contain hard particles of foreign matter imbedded in them—these should not be overlooked.

166. A series of substitutes has been arranged for use when a scale of hardness is not available; *i.e.*—

1. May be readily impressed with the finger nail.

2. Is scarcely impressed with the nail; does not scratch a plate of copper.

3. Scratches a piece of copper, but is also scratched by it.

4. Is not scratched by a piece of copper, but does not scratch glass.

5. Scratches glass slightly; is easily scratched with a knife.

6. Scratches glass easily; is scratched a little with a good knife.

7. Is not scratched with a knife, but yields to a file.

8. Cannot be filed, but scratches a rock crystal.

9. Scratches a topaz.

10. Scratches a ruby.

167. Specific Gravity.—This term is used to express the weight of a substance as compared with some other substance. It is a character of much practical importance in Mineralogy. Water is always the standard of comparison for minerals; thus, the specific gravity of water is said to be 1, that of silver 10·5, the meaning being that silver is 10½ times heavier than an equal bulk of water.

The specimen to be examined should be free from foreign matter and from decay, unless it is the specific gravity of such a specimen which is actually wanted. It should also be free from cavities; when these are suspected, the specimen should be powdered.

168. The following methods will suffice for all minerals, the first for such as are in compact masses, the second and third for similar masses, for small fragments, or for liquids.

1*st Method.*—*a.* Weigh the specimen carefully in an ordinary pair of scales.

b. Suspend it by a horsehair from below the scale-pan, let it dip well under the surface of water in some convenient vessel, as shown in fig. 557, and again weigh it. It will be found that fewer weights will balance it than in the first weighing.

c. Subtract the weight in *b* from that in *a*, the difference will be the weight of a bulk of water exactly equal to the specimen.

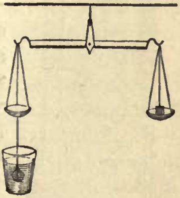

Fig. 557.

d. Divide the weight *a* by the difference *c* $(a-b)$, the quotient will be the specific gravity G, according to the formula $\frac{a}{a-b} = G$.

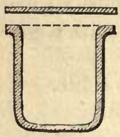

Fig. 558.

2nd Method.—Procure a small *specific gravity bottle* (or a small glass beaker of the form and size of fig. 558, having a thin glass plate ground to fit its upper edge), so arranged as to hold a known weight of water—say 50 grains. Fill it with water, insert the stopper, and wipe it dry. Now, make a counterpoise of exactly the weight of the filled bottle.

a. Weigh off any convenient quantity of the specimen less than the capacity of the bottle, and in fragments not too large to go into it.

b. Put the weighed fragments into the bottle, taking care to lose none. Of course, as the bottle was already *filled* with water, some will now run out. It is also evident that the water which runs out must be of exactly the same bulk as the mineral introduced. Having again inserted the stopper (or put on the cover), and wiped the bottle, it will be found that the counterpoise, together with a smaller number of weights than those used to balance the fragments in *a*, will produce equilibrium.

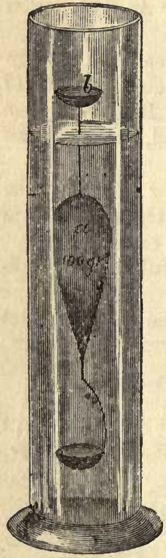

Fig. 559.

c. The difference will be the weight of the displaced water, *i.e.*, of a bulk of water equal to the specimen, and the same formula $\frac{a}{a-b}=G$ will give the specific gravity.

3rd Method. — Specific gravities are often determined by means of Nicholson's aræometer, a little instrument which is made in many forms, one of the most convenient of which is represented in fig. 559. This is a hollow, pear-shaped body (*a*), usually of brass, having a wire stem, which supports a little cup (*b*), and another suspended cup below (*c*). The whole apparatus is so arranged as just to sink in a tall jar of water to a mark (*d*) placed on the wire stem, when a given weight, called the *balance weight*, is placed in the cup *b*. The specimen to be experimented upon must not exceed this weight, which we will suppose to be 100 grains, the quantity marked upon the body of the instrument.

The fragment is placed in the cup *b*, weights are added until the instrument sinks to the mark *d* on the stem. The difference between the weight used and 100 grains, of course, equals the weight in air (*a*) of the specimen.

It is now taken from the cup *b* and placed in the cup *c*, when, as the mineral is buoyed up by the water, the instrument will rise, and more weights must be added until it again sinks to the mark *d*. This latter quantity is the weight of the water displaced by the mineral (*c*), and once more, by the formula $\frac{a}{a-b}=\mathrm{G}$, we get the specific gravity of the mineral.

When the specific gravities of two substances are known, by taking that of a mixture of the two we may find the relative weights of each of the components. Thus, knowing the total weight of a nugget of gold while partially enclosed in quartz, we may determine the weight of the gold exclusive of the quartz.

Let g = the weight of gold in a nugget.
,, G = its specific gravity.
,, q = the weight of quartz.
,, Q = its specific gravity.
,, n = the weight of the nugget.
,, N = its specific gravity.

Then $g+q=n$,

and $\frac{g}{\mathrm{G}}+\frac{q}{\mathrm{Q}}=\frac{n}{\mathrm{N}}$.

From which equations we may obtain the following—

$$g=n\frac{(\mathrm{N}-\mathrm{Q})\mathrm{G}}{\mathrm{G}-\mathrm{QN}}.$$

Thus if the specific gravity of a nugget whose weight is 11½ oz., be 7·43, taking the specific gravity of quartz at 2·62, and that of fine gold at 19·35, we shall have from the above formula—

$$g=11{\cdot}5\times\frac{7{\cdot}43-2{\cdot}62}{19{\cdot}35-2{\cdot}62}\times\frac{19{\cdot}35}{7{\cdot}43}=\frac{10703452{\cdot}5}{1243039}=8{\cdot}6107,$$

i.e., the amount of fine gold in the nugget will be 8·6107 oz.*

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* Galbraith and Haughton's *Manual of Hydrostatics.*

When a mineral is soluble in water it may be weighed in oil, alcohol, or other liquid, in which it is insoluble. The specific gravity of this latter liquid being known, or separately ascertained, and that of the mineral as compared with it being determined, its specific gravity as compared with water will be found by simple proportion.

If a mineral be lighter than the fluid used in determining its specific gravity a sinker of brass may be used. Let this be weighed, and call the weight x. Then

$$G = \frac{a}{a + x - b}.$$

The bubbles of air which attach themselves to the rough surfaces of minerals when suspended in water cause them to displace rather more water than they would otherwise, consequently the specific gravity is apt to be understated. To avoid this the bubbles should be removed by a bristle, or the water may be boiled for a minute or so, and allowed again to cool to 60°F. before the determination is made. Or the mineral may be dipped in strong alcohol, and afterwards washed in distilled water after weighing in air and before weighing in water. In this way air bubbles will be got rid of, and the true specific gravity may be ascertained without difficulty.

CHAPTER XXI.

PHYSICAL PROPERTIES—MAGNETISM, ETC.

169. Magnetism.—This property is not much used in determining unknown minerals; but it is of great importance in practical mineralogy and geology, since the instruments used in surveying are often affected by magnetic substances. The mineral which has most magnetic power is that called *magnetite,* or native loadstone. It sometimes occurs in large masses, and very frequently in minute grains, disseminated through rocks so as to render them magnetic throughout. In Sweden and the United States a magnetic needle, mounted so as to move in a vertical plane, and called a "dipping needle," has been used in the discovery and mapping of masses of magnetic iron ore which are covered with other rocks.

This is the only important or widely-distributed mineral which will attract unmagnetised metallic iron; but many minerals are attracted more or less by a magnet, or will attract a magnetised needle such as is used for surveying instruments. The ores of manganese, nickel, and cobalt have often this property in a small degree as well as many ores of iron. Some mineral substances which are not naturally magnetic become so after being heated, especially the carbonate of iron, which may be thus distinguished from several minerals which it much resembles with great ease and certainty.

A convenient instrument for a mineralogist is a pocket knife—one blade of which is magnetised. Such a knife may be used in testing fine particles or powdered minerals for magnetism.

Ordinary magnetic substances, as iron, nickel, cobalt, manganese, and their ores, are generally attracted by either pole of a magnet; but magnetite has sometimes distinct magnetic polarity, that is, a particular point will *attract* one end of a freely suspended needle, while it *repels* the other end; native bismuth and some few other substances *repel* both ends of such a needle. These are said to be *diamagnetic.*

170. Electricity.—Many minerals become electrified and capable of attracting light bodies after being heated or rubbed. These are said to be *pyro-electric* or *frictio-electric.* Friction with a feather is sufficient to excite electricity in some varieties of *blende,* while most *tourmalines* are pyro-electric. Some minerals, such as *topaz,* will retain their electricity for hours, others lose it in a few minutes.

A very simple and delicate electroscope for testing this property may be made from a bent glass rod, from which a minute fragment of gilt paper or gold leaf is suspended by a single fibre of silk. On approaching a substance whose electricity has been excited by any method, the suspended fragment will move towards it.

Electricity is of two kinds, each being the opposite or complement of the other. That excited by rubbing a glass rod with silk is called *vitreous* or *positive,* while the electricity developed by rubbing sealing-wax or sulphur with wool is called *resinous* or *negative.* Nitre, fluor, aragonite, apatite, and epidote, acquire negative electricity by friction, whilst sulphur, wolfram, tantalite, mispickel, and cassiterite develop positive electricity. Some crystals while exposed to an increasing temperature exhibit positive electricity at some points of their surface and negative at other points; while the temperature is falling these points are charged with the *opposite* electricities. The points at which an ascending temperature develops positive electricity are called *analogous* poles, and those which develop negative electricity under the same circumstances *antilogous* poles.

171. Phosphorescence. — Many minerals after being *heated, exposed to light, rubbed,* or *electrified,* seem to glow or shine in a peculiar manner if taken into a dark place. This property is called phosphorescence. Thus if a piece of fluor-spar, especially the massive variety called *chlorophane,* be placed on a fire shovel and heated over the fire, or in a glass tube and heated over a spirit lamp, it will when taken into a dark place be seen to shine with a bright green light.

If an electric shock be passed through a piece of chlorophane, a similar phosphorescence will be produced. It has long been observed of *diamonds* that, if taken into a dark room after exposure to the light of the sun, they will shine brightly.

Minerals which become phosphorescent from heat are sometimes called *pyro-phosphoric*, from friction *frictio-phosphoric*, from electricity *electro-phosphoric*, from exposure to the light of the sun *helio-phosphoric*. These latter are said to be *insolarised*, as is the case with some varieties of *calcite*.

Sometimes a pyro-phosphoric substance by repeated heating loses its property of acquiring phosphorescence. This may be occasionally restored by passing a few electric shocks through the substance.

Among pyro-phosphoric minerals, some, as certain varieties of fluor and diamond, begin to shine in the dark at a temperature below that of boiling water. A great many minerals shine at a temperature much below a red heat.

Among minerals which become phosphorescent by friction may be mentioned the *blende* from Kapnik, which shines when scraped or scratched. Two pieces of *quartz* will shine if rubbed together in the dark, either in air or under water, and some varieties of *dolomite* and *calcite* emit light when struck by a hammer.

In grinding siliceous minerals, so as to make thin sections for microscopic purposes, phosphorescent light is almost always produced.

172. Heat.—We have already stated that heat develops electricity and magnetism in minerals under certain conditions. M. Senarmont discovered, in 1847, that the *conduction* of heat in crystals has a direct relation to their crystalline form, in a manner precisely in accordance with their relations to light.*

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* *Comptes Rendus*, 1847, p. 708.

CHAPTER XXII.

OPTICAL PROPERTIES—COLOUR, ETC.

173. Optical Properties.—Among those properties of minerals which relate to or depend upon Light, and which are recognised by the eye, *colour* is naturally the first to be observed.

Among other optical properties we may mention *streak*, *lustre*, *diaphaneity* or *transparency*, *chatoyancy*, *iridescence*, *opalescence*, *refractive power*, and *polarising power*.

174. Colour.—The colours of minerals having metallic lustre often afford useful aids to their recognition. In minerals having *non-metallic* lustre, on the contrary, the colour is liable to be much altered by the presence of minute proportions of accidental impurities, or from other causes, so that it is a character of little *specific* importance. Many *varieties* of the same mineral species are, however, named solely from their colour. Thus *schorl* is simply black tourmaline.

Werner arranged a long series of colours to which he proposed that all minerals should be referred. Commencing by separating *metallic* from *non-metallic* colours, he classed the former into one group, passing from pinchbeck-brown through bronze-yellow, tin-white and steel-grey to iron-grey and black. The non-metallic colours were first divided into *white*, *grey*, *black*, *blue*, *green*, *yellow*, *red*, *brown*, and these again subdivided. The variations of tint are so great in most species that "Werner's colours" are not much referred to now.

175. Pleochroism.—Many crystalline minerals appear to be of two or more distinct colours when viewed in different directions by transmitted light. This property is called *dichroism* when the different tints are two in number, *trichroism* when there are three tints, and, generally, *pleochroism*. Even when the different tints are not evident to the unassisted eye, they may be detected by the use of the *dichroiscope.*

176. **Chatoyancy**[*] is a property present in many minerals, especially in *Labradorite.* It consists of a peculiar change of colour of the light reflected from the mineral, which is observable when the substance is slightly moved about, and which is supposed to resemble what is seen in a cat's eye. It is due to a peculiar internal structure in the mineral.

177. **Iridescence**[†] is a brilliant play of colour observable locally in the fissures of many minerals when cracked, or between their cleavage planes. It appears to be due to the same cause as "Newton's rings," and can only be explained to students who have a knowledge of the *undulatory theory* of light.[‡] It may be readily produced by heating a piece of quartz and throwing it into water, or by striking a blow enough to *crack* but not to *break* it. It may generally be seen in *selenite,* and is the chief cause of the beauty of *fire-opal.*

178. **Opalescence** is due to a peculiar subtransparent condition of matter, such as is seen in many varieties of opal. A good idea of opalescence may be got by filling a flask with milk and water and putting a light behind it.

179. **Fluorescence** is a property possessed by *fluor* and other substances of absorbing certain rays of the solar spectrum, and subsequently emitting rays of different refrangibility. They consequently appear of different colours when viewed by transmitted and reflected light. The phenomenon was first observed by Prof. Stokes in green fluor-spar, which *fluoresces* with a fine indigo-blue colour.

180. **Streak.**—The colour of the powder of a mineral. When the lustre is *metallic* the streak is dark, often darker than the colour of the mineral; when non-metallic it is usually lighter than the colour.

Hematite may be readily distinguished from *limonite* which it often resembles, by its streak being *red* instead of *brown. Wolfram,* too, can be at once distinguished from *blende* by its darker streak. This test admits of being tried in cases where the specific gravity cannot be easily determined, as in *im-*

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[*] *Chat,* a cat.

[†] *Iris,* a rainbow.

[‡] See Lees' *Acoustics, Light, and Heat,* p. 165.

bedded crystals. It may also be usually tried without injury to the specimen.

The colour of the streak of a mineral is best determined by rubbing the specimen on a slightly roughened plate of white porcelain, when, if not too hard, some of it will be rubbed off. Very often a scratch with a knife suffices, or rubbing with a file; but the mark thus made in the specimen, "the scratch," must be distinguished from the colour of the abraided particles—the streak—since it sometimes differs from it very markedly, as in the case of *chalcopyrite*, in which the *streak* is nearly black, while the scratch is yellow and shining.

181. **Lustre.**—Most minerals shine with a peculiar *lustre*, which differs in different species, and depends chiefly upon their "index of refraction" and structure. The chief varieties of lustre are:—

a. Metallic, as seen in *pyrites* and *graphite.*

b. Adamantine (diamond-like), as seen in the *diamond* and some varieties of *quartz.*

c. Resinous, as seen in some kinds of *blende* and *cassiterite.*

d. Vitreous (glassy), as in *fluor* and *calcite.*

e. Pearly, as in *pearl-spar* and *stilbite.* This is often seen on the cleavage planes of minerals not otherwise pearly. It frequently accompanies incipient decomposition, as in *Murchisonite.*

f. Waxy.—Seen in some varieties of *talc.*

g. Silky, as in "satin-spar" (both kinds), and in most minerals having fibrous structure.

Each of the above varieties of lustre may vary in degree; thus we may have—

h. Splendant, as seen in *specular iron* and *galena.*

i. Brilliant, as in *galena.*

j. Shining, as in *dolomite.*

k. Glimmering, as in *serpentine.*

Different kinds of lustre sometimes occur on different faces of the same crystal, not accidentally, but as distinct qualities of the particular faces. Such differences, for example, occur in anhydrite. A few minerals have no lustre, these are said to be *dull.* Many varieties of minerals have a lustre not perfectly metallic, these are said to be *sub-metallic.* The true metallic lustre is only to be seen in minerals which are almost or entirely opaque, but not in all such.

182. **Diaphaneity or Transparency.**—A general term expressing the degree of transparency or opacity of mineral substances. The several degrees are :—

a. Transparent.—Outlines of objects may be seen distinctly through thick layers.

b. Semi-transparent.—Outlines visible, but indistinctly.

c. Translucent.—Light passes through, but no outline can be seen.

d. Sub-translucent.—Light is only transmitted through thin edges or splinters.

e. Opaque.—No light is transmitted.

CHAPTER XXIII.

OPTICAL PROPERTIES—REFRACTION, ETC.

183. Refraction.—When a ray of light falls upon a transparent substance, in a direction at *right angles* to its surface, it passes through the substance without change of direction. When a similar ray, however, falls *obliquely* upon the surface, its direction is always changed in passing through. Thus let *aa, bb, cc* represent three rays of light passing from the lamp *h* (fig. 560) on to the plate of glass *fg*, the ray *aa*, falling upon its surface perpendicularly, will pass through without change of direction; while the rays *bb, cc*, which fall obliquely, will be bent out of their course towards the perpendicular at *b* and *c* while passing through the glass; but will pass on in a line parallel to their original direction afterwards.

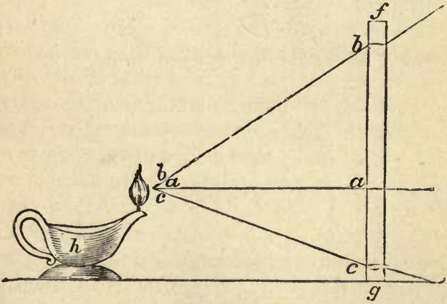

Fig. 560.

This bending is called *refraction*, and it is possessed by all transparent bodies, though some substances bend or refract the rays of light more than others.

184. Law of Refraction.—If we describe a circle with any convenient radius OA, fig. 561, and draw A′F, DG perpendicular to AB; then it is found that whatever the magnitude of the angle A′OA, the relation between A′F and DG is always the same for the same transparent substance. A′F is the "sine of the angle of incidence," and DG the "sine of the angle of refraction;" and $\frac{A'F}{DG} = n$, which is the *index of refraction.**

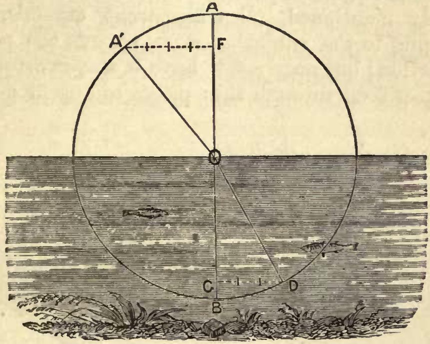

Fig. 561.

185. Double Refraction.—On looking at a bright point through two inclined faces of a prism, made of a crystal not belonging to the cubical system, two images or *spectra* will be observed. This property of not only refracting rays of light falling obliquely, but of splitting each ray into two, is possessed by all transparent crystalline substances which do not belong to the cubical system.† In pyramidal and hexagonal crystals, one portion of the ray called the *ordinary ray* follows the law of refraction, but the other portion called the *extraordinary* ray is refracted—sometimes *more,* sometimes *less,* than the other, but always in accordance with a different and very complicated law. The refraction of

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* This subject is more fully explained in Lees' *Acoustics, Light, and Heat,* forming part of the present Advanced Series.

† A few cubical minerals possess a peculiarly modified structure in relation to this law, but it is quite of a different nature to that which is now described.

the extraordinary ray is *greater* than that of the ordinary ray in *apophyllite, zircon, rutile, cassiterite, brucite, quartz, hematite,* and *pyrargyrite.* It is *less* than that of the ordinary ray in *wulfenite, idocrase, anatase, mellite, nitratite, apatite, calcite, dolomite, pyromorphite, biotite, nephelite, sapphire, tourmaline,* and *cinnabar.* In rhombic, oblique, and anorthic crystals neither ray is refracted according to the "law of sines," except in particular directions.

As already mentioned, all transparent crystals, except those belonging to the cubical system, possess the power of double refraction; but only a few have it so powerfully as to cause an object seen through thin pieces to appear double.

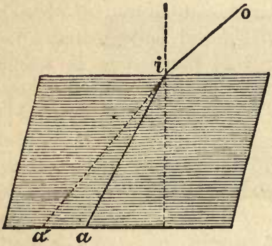

Fig. 562.

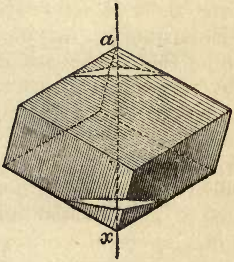

Fig. 563.

Of all substances possessing the property of double refraction, that called "Iceland spar," or *doubly refracting spar*—a very clear and transparent variety of calcite—shows it best. It is owing to this property of Iceland spar that all objects seen through that substance appear double, except when seen in one particular direction, which is the optic axis, or axis of no double refraction. In the hexagonal and tetragonal systems the optic axis is the principal axis of the crystal. If a rhomboid of Iceland spar, fig. 562, be placed over a dot on a sheet of paper, the dot will appear doubled, the ray *oi* being split up into the two rays *ia* and *ia'*, and in whatever position the rhomboid is placed, an imaginary line joining the two dots will be parallel to the principal axis of the crystal. Let now the two three-faced solid angles, *which are formed by the junction of three equal and similar angles,* be ground down so as to produce three triangular planes perpendicular to the principal axis, as in fig. 563, and parallel to each other, and let these planes ($\infty \infty 1$) be polished. It will be found that a dot looked at through these planes will not appear double. In every other direction but this there will be double refraction. In rhombic, oblique, and anorthic crystals, there are two optic axes, and such crystals are said to be *biaxial.*

186. Polarization.—A ray of light which has passed through a doubly refracting crystal in any other direction than its optic axis, suffers a peculiar change called *polarization.* Such a ray is not again divided into two portions if made a second time to pass through a doubly refracting crystal. Moreover, there is for every shining non-metallic substance a particular angle, varying with the substance, at which it is found that such a *polarised ray* cannot be reflected.

Light which has acquired these two properties is called *polarised light;* but these peculiar changes may be impressed upon ordinary light, not only by its passing through a doubly refracting substance, but also by being simply reflected at a particular angle from a non-metallic reflector; or by being refracted at a particular angle through a series of parallel plates of glass or other transparent substances which do not possess the property of double refraction, as in fig. 564 *cc;* or by simply passing through a Nicol's prism, fig. 565, or a "tourmaline plate" cut parallel to the principal axis of the crystal. If a crystal of tourmaline be cut into thin plates parallel to its principal or optic axis, a pencil of light passing through will be split into two rays. One of these will be completely absorbed by the tourmaline if the plate be not too thin, while the other will pass through the plate. The reason of this is not certainly known, but it is probable somewhat as follows:—Regarding the ray of ordinary light as consisting of very rapid undulations of the luminiferous ether in every possible direction, and supposing the structure of the tourmaline plate to resemble a very fine grating, the bars of which are parallel to the optic axis, then it is easy to see that all the vibrations of the incident ray, except those which are vertical like the bars, will be stopped or absorbed; but the vertical undulations will still be transmitted, and consequently the light will still pass through, although it will be much fainter than the original ray. If now a second plate (or indeed any number of plates) be placed in a similar position to the first (*a*, fig. 566), the ray of light will be no farther affected, except in so far as the want of transparency of the substance is concerned; but if it be placed diagonally as at *b*, the light will nearly all be stopped, and if as at *c* (the supposed "grating" being at right angles) the light will be completely stopped. If a plate of tourmaline be so arranged that it can be made to revolve through a complete circle, it will be found that there are two positions in which polarised light, *i.e.*, light vibrating in one plane, does not pass, and these are opposite each other, or 180° apart.

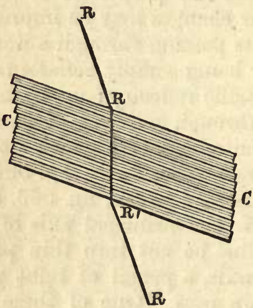

Fig. 564.

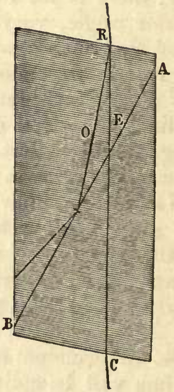

Fig. 565.

If a ray of light, after being polarised, be made to pass again through a doubly refracting crystal, it becomes *depolarised,* and again converted into ordinary light. This property affords a ready test of double refraction in mineral substances. If a plate with parallel surfaces be cleaved or cut from such a substance, and placed between two plates of tourmaline in crossed position (fig. 566, *c*), in which it will be remembered they are totally opaque, the transparency is restored. In addition, the plate is brilliantly coloured if of a certain degree of thinness, varying with the substance tested. The plate of tourmaline through which the light in passing is polarised is called the *polariser*, the doubly refracting substance, the *depolariser*, and the other plate of tourmaline through which it is seen, the *analyser*. A convenient instrument for use in testing minerals for this property of double refraction is the tourmaline pincette, shown in fig. 567, in which two plates of tourmaline are arranged so that either may be rotated through any required angle.

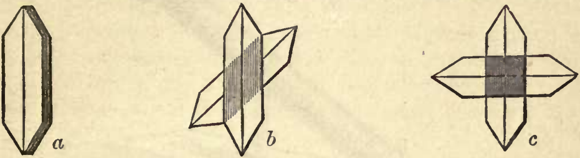

Fig. 566.

Any non-metallic reflector placed at the proper angle, a bundle of glass plates, or the Nicol's prism, may be used instead of the tourmaline, either as a polariser or analyser; and an instrument arranged with any two of these for observing such phenomena, is called a *polariscope*.

187. Nicol's Prism.—This is a rhomb of Iceland spar which has been cut across obliquely, as at AB, fig. 565, parallel to the principal axis; the two parts are then finely polished and cemented together again. The action of the "Nicol" upon light is as follows:—R is a ray of ordinary light which, on entering the Nicol, is split up into the ordinary ray O, and the extraordinary or polarised ray E. O, meeting the Canada balsam at a very low angle, is reflected, as shown, and is so got rid of; but E, meeting it at a greater angle, passes through, and emerges at C unaltered. For experiments on microscopic crystals, the polariser usually consists of a Nicol's prism, or a bundle of glass plates placed beneath the stage; a plate of tourmaline held above the eye-piece, or a second Nicol's prism placed in the body of the microscope, just above the object-glass, serves well for an analyser.

Fig. 567.

188. Table Polariscope.—A sheet of glass, with its under side blackened, forms an excellent polariser either for the microscope or for the table polariscope, fig. 568; where *a* is the blackened mirror fixed on the board B. In the centre of the board is an upright pillar supporting the tube *cd*, the axis of which is directed towards the mirror at an angle of $35\frac{1}{2}°$ (the complement of $54\frac{1}{2}°$, the polarising angle for glass).

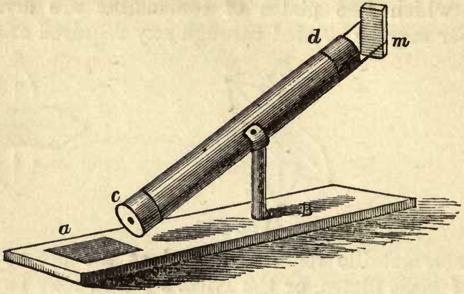

Fig. 568.

At *c* is a cap having a small hole in it, and at the other end a second cap *d*, supporting the mirror *m*, which is used for experiments upon simple polarization of light. When experimenting upon minerals, the best plan is to replace this with a Nicol's prism, or a plate of tourmaline. The material to be examined, which should be from $\frac{1}{8}$ to $\frac{1}{4}$ inch thick, is fixed over the hole with a bit of wax, and viewed through the analyser at *d*. If the object is a slice from a crystal in the hexagonal or tetragonal systems cut parallel to ∞ ∞1, say a hexagonal prism of calcite, a black cross surrounded by a series of coloured rings, as in fig. 569, will be seen, and as the analyser is made to revolve the cross will change from black to white, and the colours of the rings will change to their complementaries, *i.e.*, red to a green, and violet to orange, as in fig. 570. The intervals between the rings are smaller as the thickness of the slice increases, or, the thickness being the same, as the doubly refractive power increases.

189. Circular Polarization—In quartz exceptional phenomena are observed, as compared with other hexagonal crystals. With a slice cut parallel to ∞ ∞1, there are in every position of the analyser the rings without the cross, the centre of the

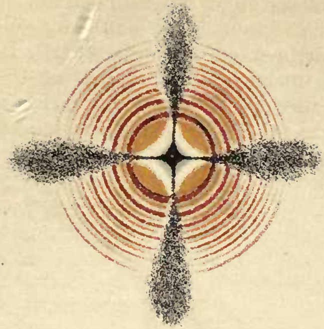

Fig. 569

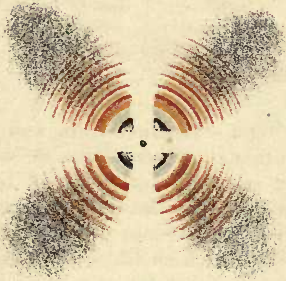

Fig. 570

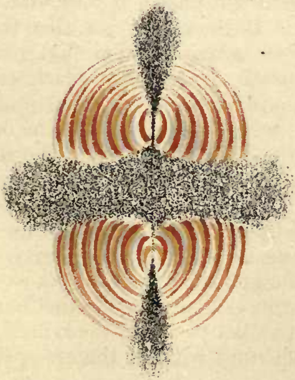

Fig. 571

inner ring being of one colour, which passes through all the tints of the spectrum to its complement as the analyser or polariser is rotated. In some specimens the change is from red to violet, as the rotation is from left to right, and in others the reverse is observable, the polarization being *right-handed* and *left-handed* respectively.

With a plate of any biaxial crystal, *i.e.*, belonging to the rhombic, oblique, or anorthic systems, *e.g.*, nitre, the double system shown in fig. 571 is observable, when the Nicols are crossed. If the analyser be revolved the dark cross will become white, and will break up into two arcs as the plate of crystal is made to rotate, the polariser being fixed. The points AB are the optic axes.

190. The Dichroiscope.—This is an instrument devised by Haidinger for testing the pleochromatism of minerals. It is drawn in section, nearly full size, in fig. 572. A is a cleavage rhombohedron of calcite, having two small glass prisms CC of 18° each cemented on to the ends by Canada balsam. At one end is a convex lens, or combination of lenses, D, of such focal length as to show distinctly an object, about ·4 inch from the end L, seen by the eye at D. At the other is a stop having an opening L about ·12 inch square.

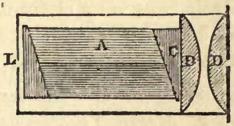

Fig. 572.

On looking through the prisms with the eye at D, two images of L will be seen just in contact with each other. The light of one image is polarised in a plane through the short diagonal of A (or parallel to the paper), while that of the other image will be polarised on a plane at right angles. When a pleochromatic crystal is placed before L at the distance of distinct vision, and the prism turned until its planes of polarization coincide with those of the crystal, the two images of the square opening will show the colours of the oppositely polarised pencils of which the transmitted light is composed, and to which the pleochromatism is due.

CHAPTER XXIV.

CHEMICAL CHARACTERS—TASTE, ODOUR, ETC.

THE chief of the so-called chemical characters of minerals, or those which depend upon chemical composition, are—*taste, odour, solubility, fusibility,* and *volatility.*

191. Taste is a character of great importance in the case of a few minerals.

Thus *cyanosite, goslarite, melanterite, halite* or common salt, *kalinite, nitre, nitratite,* and a few other mineral substances, may be at once known by their taste, which is in each case very characteristic.

The chief varieties of taste observed in mineral substances are the following:—

a. *Metallic*—the taste of native metals.
b. *Metallic astringent*—the taste of the vitriols.
c. *Sweetish astringent*—the taste of alum.
d. *Saline*—the taste of common salt.
e. *Alkaline*—the taste of nitrate of soda.
f. *Cooling*—the taste of nitre.
g. *Bitter*—the taste of Epsom salts.
h. *Sour*—the taste of sulphuric acid.

The only minerals which have *distinct* taste are those which are soluble in water.

192. Odour is occasionally of importance. Thus many minerals containing alumina or magnesia give off a peculiar earthy smell when breathed upon; others, which contain sulphur or arsenic, when broken, rubbed, or heated, yield a characteristic smell. The chief varieties of odour are the following:—

a. *Alliaceous* — the odour of garlic. It is observed on rubbing, heating, or breaking ores containing *arsenic.*

b. *Horse-radish odours* — the odour of decaying horse-radish. It is observable on heating or melting substances containing *selenium.*

c. Sulphureous—the odour of burning sulphur, observable on heating, breaking, etc., many substances containing *sulphur.*

d. Fetid—the odour of rotten eggs. It is given off by some varieties of quartz, barytes, and limestone when broken or rubbed.

e. Argillaceous—clayey. It is given off by serpentine, and other substances containing magnesia.

193. Solubility.—This is determined by treating a powdered mineral with *water*, *acids*, or *alkalies.* The chief solvents used (and the order in which they are applied) are as follows:—

a. Water.

b. Hydrochloric acid—Dilute at first; stronger afterwards if necessary.

c. Nitric acid—Dilute at first; then strong.

d. Sulphuric acid.

e. Aqua regia—A mixture of nitric and hydrochloric acid.

f. Special solvents, such as oxalic acid, ammonia, etc.

To ascertain the solubility of a mineral, a few grains of its powder should be placed in a test-tube or watch glass, and warmed with a few drops of the solvent. If the substance be *freely* soluble, and it is only in such cases that this test is valuable in determinative mineralogy, the powder will rapidly disappear. Any *effervescence, peculiar odour,* change of *colour* or *appearance,* or *insoluble residue,* should be carefully noted. Thus sulphides may often be recognised by the unpleasant odour of sulphuretted hydrogen which is given off when they are treated with hydrochloric acid; while all carbonates effervesce strongly under similar treatment with warm acid if not with cold.

a. Water.—Sulphates, such as *melanterite,* and *cyanosite,* and generally minerals having distinct taste, are soluble in water.

b. Hydrochloric acid.—Many oxides, as *limonite* and *göthite,* dissolve quietly in HCl, without effervescence or evolution of vapour; others, as *pyrolusite,* give off chlorine, especially when warmed with the acid; others again, as *cassiterite,* are not attacked by the acid.

Some sulphides, as *blende* and *antimonite,* give off vapours of H_2S when treated with HCl, others, as pyrites, are not perceptibly affected. Tungstates, titanates, molybdates, and vanadates are only partially decomposed, the first leave a yellow powder (tungstic acid), the others white powders (titanic, molybdic, and vanadic acids); tungstic and titanic acids are insoluble in an excess of the solvent, the others are soluble. A few silicates are soluble completely in HCl, others are decomposed, leaving deposits of gelatinous or pulverulent silica; others are not affected by the reagent.

The following table shows the behaviour of the most common silicates when treated with acids :—

a. Completely soluble in dilute HCl.

Allophane.
Collyrite.
Gismondite.
Keilhauite.
Yttrotantalite.
Zeagonite.

b. Decomposed by HCl *separating gelatinous silica.*

Ædelforsite.
Allanite.
Analcime.
Apophyllite.
Barsowite.
Cancrinite.
Cerite.
Chabasite.
Chamoisite.
Chondrodite.
Cronstedtite.
Datholite.
Dioptase.
Eudialite.
Gadolinite.
Gehlenite.
Gmelinite.
Haüyne.
Helvine.
Heulandite.
Hisingerite.
Humboldtilite.
Hyalosiderite.
Ittnerite.
Knebelite.
Laumonite.
Lievrite.
Meerschaum.
Meionite.
Mesotype.
Mesolite.
Nepheline.
Natrolite.
Nontronite.
Okenite.
Pectolite.
Phillipsite.
Schrotterite.
Siderochisolite.
Sodalite.
Spadoite.
Stilbite.
Tscheffkinite.
Thomsonite.
Thorite.
Wollastonite.

c. Gelatinise in HCl (after ignition only).

Axinite.
Epidote.
Garnet.
Idocrase.
Lepidolite.
Prehnite.

d. Separate pulverulent silica.

Amphodelite.
Anorthite.
Antigorite.
Baryta-harmotome.
Chonicrite.
Chrysocolla.
Epistilbite.
Lepidomelane (in pearly scales).
Leucite.
Pennine.
Pollux.
Pyrosclerite.
Rhyacolite.

e. Separate silica, gelatinous or pulverulent, in different varieties.

Anthosiderite.
Brewsterite.
Clintonite.
Faujasite.
Labradorite.
Margarite.
Palagonite.
Porcellanite.
Pyrargillite.
Scapolite.
Tachylite.
Villarsite.
Wöhlerite.

f. Partially decomposed only.

Acmite.
Batrachite.
Bole.
Chloropal.
Cordierite.
Edingtonite.
Glaucophane.
Isopyre.
Miloschin.
Sordawalite.
Stilpnomelane.
Garnet.

g. Decomposed by H_2SO_4 *not by* HCl.

Biotite.
Halloysite.
Olivine.
Tourmaline (after ignition).
Damourite.
Agalmalolite.
Chlorite.
Onkosine.
Ottrelite.
Kaolin (after ignition).
Pyrochlore.
Pyrosmalite.
Schiller spar.
Serpentine.
Steatite.
Sphene.
Pyrophillite.

h. Scarcely affected by HCl or H_2SO_4.

Albite.
Andalusite.
Augite.
Diallage.
Hypersthene.
Beryl.
Castor.
Chloritoid.
Couzeranite.
Kyanite.
Cymophane.
Emerald.
Euclase.
Fahlunite.
Orthoclase.
Gedrite.
Hornblende.
Hypochlorite.

Jeffersonite.
Karpholite.
Oligoclase.
Petalite.
Phenakite.
Pitchstone.
Muscovite.
Saussurite.
Spodumen.
Staurolite.
Talc.
Topaz.
Wichtysite.
Wörthite.
Zircon.

c. Nitric acid.—This is chiefly used in treating native metals, and metallic oxides and sulphides. Many of the metals, as *copper* and *bismuth*, when so treated, decompose the acid, and give rise to red vapours; so also do the suboxides, as *cuprite*. Sulphides often afford a deposit or floating cake of sulphur; tungstates, titanates, vanadates, and molybdates behave as with HCl. Minerals containing arsenic and antimony often afford insoluble oxides of these substances, as white powders. *Cassiterite* is not affected by nitric acid.

d. Sulphuric acid is rarely used as a mineral solvent, but some silicates, as *kaolin*, are more readily attacked by it than by hydrochloric acid. A few minerals, as *atacamite* and *chlorargyrite*, are soluble in NH_3.

c. Aqua regia may be used for the decomposition of obstinate sulphates and arsenides, it will also dissolve gold and platinum, the latter somewhat slowly.

194. Insoluble Minerals.—These are very numerous—the term is generally applied to those which are insoluble in HCl, HNO_3, H_2SO_4, and aqua regia; among them we may mention *diamond*, *corundum*, *spinel*, *chromite*, *diaspore*, *rutile*, *cassiterite*, *quartz*, *chlorargyrite*, *barytes*, *celestite*, *anglesite*, *xenotime*, *lazulite*, *childrenite*, *amblygonite*, and *boracite*, besides the silicates mentioned above; of these, the silicates are soluble in HF.

195. Fusibility.—This is a character of very great importance, and it is convenient to have a scale of reference. The *scale of fusibility* most usually adopted is the following:—

1. Antimonite.
2. Natrolite.
3. Almandine, a variety of garnet.
4. Actinolite.
5. Orthoclase.
6. Bronzite.

Antimonite is so fusible that splinters may be readily melted by being held in the flame of a candle; while bronzite is infusible. The others are of intermediate fusibility. Of course a mineral is tested *per se* to determine its fusibility, as many infusible minerals become fusible on adding other substances.

196. Volatility.—This is tested by heating fragments of minerals in *closed* or *open* tubes, or while resting upon charcoal or other "supports." Some minerals are completely driven off in vapour by such treatment, either with or without previous fusion, while others are quite unchanged. Further reference to the fusibility and volatility of minerals will be made in the chapter on the use of the blowpipe.

CHAPTER XXV.

CHEMICAL CHARACTERS—BLOWPIPE ANALYSIS.

197. THE student of Mineralogy should have a considerable acquaintance with the principles of Inorganic Chemistry before entering upon this advanced course; as, otherwise, his progress will be slow, and, moreover, he will have but an imperfect appreciation of the important chemical relations of minerals. It is also desirable that he should have sufficient knowledge of Practical Chemistry to enable him to make at least a *qualitative* analysis of any ordinary mineral substance. *

198. Elements.—The world and all it contains is made up of about sixty-eight perfectly distinct substances. These are called elements by chemists, because hitherto they have not been able to *decompose* them.

Of this large number of elements many are very rare; while the most common minerals are made up of little more than a dozen. Those which occur most frequently in mineral substances are the gases oxygen, hydrogen, nitrogen, chlorine, and fluorine; the non-metallic solids sulphur, carbon, silicon, and boron; and the metals potassium, sodium, lithium, calcium, magnesium, aluminium, and iron. In chemistry, the elements are usually for brevity and greater convenience indicated by letters or symbols, rather than by their full names. In the following tables the symbols and atomic weights are placed against the names of the respective elements to which they belong.

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* Such information may be gained from the works on *Inorganic* and *Practical Chemistry*, forming part of "Collins' Elementary Science Series."

A.—METALS.

Name.	Symbol.	Atomic or Unit Weight.
Aluminium	Al.	27·5
Barium	Ba.	137·
Bismuth	Bi.	210·
Cadmium	Cd.	112·
Cæsium	Cs.	133·
Calcium	Ca.	40·
Cerium.	Ce.	92·
Chromium	Cr.	52·5
Cobalt	Co.	55·8
Copper	Cu.	63·5
Didymium	D.	96·
Erbium	E.	112·
Glucinum	G.	9·5
Gold	Au.	197·
Gallium	G.	
Hydrogen *	H.	1·
Indium	In.	76·
Iridium	Ir.	197·
Iron	Fe.	56·
Lanthanum	La.	92·
Lead	Pb.	207·
Lithium	Li.	7·
Magnesium	Mg.	24·
Manganese	Mn.	55·
Mercury	Hg.	200·
Molybdenum	Mo.	96·
Nickel	Ni.	59·
Niobium	Nb.	94·
Osmium	Os.	199·
Palladium	Pd.	106·
Platinum	Pt.	197·
Potassium	K.	39·
Rhodium	Ro.	104·
Rubidium	Rb.	85·
Ruthenium	Ru.	104·
Silver	Ag.	108·
Sodium	Na.	23·
Strontium	Si.	87·5
Tantalum	Ta.	182·
Thallium	Tl.	204·
Thorinum	Th.	238·
Tin	Sn.	118·
Titanium	Ti.	50·

* Hydrogen is here placed with the metals, because in the majority of its properties and reactions it more resembles metals than metalloids.

METALS—*Continued.*

Name.	Symbol.	Atomic or Unit Weight.
Tungsten	W	184·
Uranium	U.	120·
Vanadium	V.	51·
Yttrium	Y.	62·
Zinc	Zn.	65·
Zirconium	Zr.	89·

B.—SEMI-METALS.

Name.	Symbol.	Atomic or Unit Weight.
Antimony	Sb.	122·
Arsenic	As.	75·
Tellurium	Te.	129·
Bismuth *	Bi.	210·

C.—METALLOIDS.

Name.	Symbol.	Atomic or Unit Weight.
Boron	B.	11·
Bromine	Br.	80·
Carbon	C.	12·
Chlorine	Cl.	35·5
Fluorine	F.	19·
Iodine	I.	127·
Nitrogen	N.	14·
Oxygen	O.	16·
Phosphorus	P.	31·
Sulphur	S.	32·
Silicon	Si.	28·
Selenium	Se.	79·5

199. Compounds.—Elements sometimes occur in a nearly pure state, *e.g.*, native sulphur and native gold. More usually, however, two or more elements are combined together forming *compounds, e.g.*, water, tin-ore. The more commonly occurring natural compounds are *oxides, sulphides, chlorides, fluorides, carbonates, sulphates, silicates, arseniates,* and *phosphates.*

200. Formulæ.—In most descriptions of minerals, the chemical composition is indicated by a group of symbols combined into what is called a *formula.* Thus, cerussite or carbonate of lead has a composition indicated by the formula $PbCO_3$. From this formula, and by the aid of the column of atomic or unit weights in the above table of the elements, it is easy to calculate the *percentage composition,* or the proportion of lead, carbon, and oxygen present in each hundred parts, as shown in the *Elementary Mineralogy* belonging to the present series.

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* Bismuth is often placed with the semi-metals rather than with the metals.

parts, as shown in the *Elementary Mineralogy* belonging to the present series.

After making an analysis of a mineral, it is often desirable to ascertain what formula will best agree with the percentage obtained. The mode of doing this is to divide each percentage by the atomic weight of the component in question, and then to divide each of the quotients obtained by the lowest. The result of this division gives the number of atoms of each component present in the compound. Generally, however, with mineral substances, the percentages do not exactly agree with those proper to any formula, owing to the impurities constantly present, and also to the *isomorphism* referred to in Art. 144.

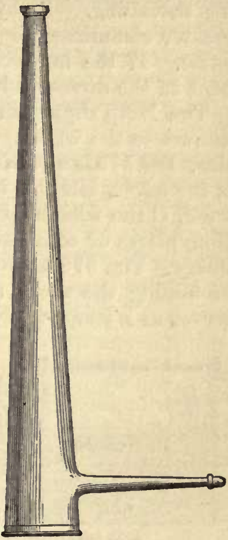

Fig. 573.

201. **The Blowpipe** is a cheap and very convenient instrument for directing the flame of a lamp or candle, and of concentrating its power upon a mineral so as to ascertain the effect of heat upon it. A very convenient blowpipe is that of Dr. Black, shown in fig. 573. In its cheapest form it is made of japanned tin, and may be obtained for a few pence. For delicate work two platinum jets of different sizes should be used. Many other kinds of blowpipe have been devised, some of which give a continuous blast, and may be worked by the hand or the foot. These are described in special treatises on the blowpipe; but the one above described will be found quite sufficient, if properly used, for all mere determinative purposes.

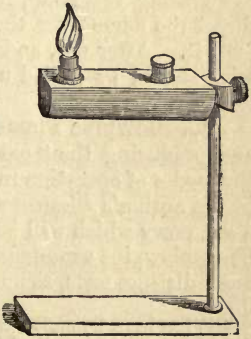

Fig. 574.

202. The Blowpipe Lamp, fig. 574, which has a large *flat** wick, will be found to be very convenient, especially if fed with olive oil, but a thick candle is perhaps more convenient for travelling. Many persons prefer to use gas from its greater cleanliness, but it is not so good for a "reducing" flame. If the lamp or candle be used, the wick should be bent in the direction in which the flame is to be blown.

The lamp shown in figs. 575 to 578, is the best which is known to the writer. The figures are drawn half the real size. Fig. 575 is a vertical section of the whole lamp, where A A is the cover, EE the body of the lamp, BB the "Freiberg" wick, C the wick-holder of tinplate, D the wax or composition pieces of composite candle, "night lights," or ordinary tallow. Fig. 576 a view from above; fig. 577 shows the mode of folding the wick; and fig. 578 the tinplate cover which serves as a stand while the lamp is in use.

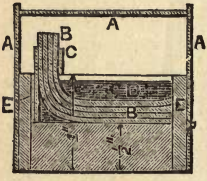

Fig. 575.

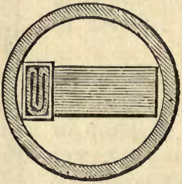

Fig. 576.

Fig. 577.

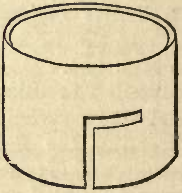

Fig. 578.

In using the lamp, it is well after lighting the wick to direct the flame over the grease for a little time so as to melt it. After use, and while the grease is still melted, the wick should be pulled up about $\frac{1}{8}$ of an inch before the wax solidifies.†

203. Blowpipe Flames.—The mode of using the blowpipe and producing the "oxidising" and "reducing" flames, and the modes of operation in testing minerals, are fully described in the author's *Elementary Mineralogy.* We merely give here a summary which will be convenient for reference. The complete blowpipe examination of a mineral consists of eight or more distinct tests, some of which may often be omitted after

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* It has been wrongly drawn with a *round* wick.

† This lamp is described by Dr. C. Le Neve Foster in the *Mineralogical Magazine,* No. 1, Aug. 1876.

a little experience has been acquired. By these tests, and a few special tests indicated or suggested by the behaviour of the substance itself, a skilful operator can discover the presence or prove the absence of nearly every one of the elements mentioned in Art. 198, and can even form a good approximation to the proportions present. The fragment of mineral operated upon called the "assay," should not generally be larger than a mustard seed, a small assay being much more manageable than a larger piece.

204. Blowpipe Operations.—The usual course of operation is—

(1). Heating in "matrass" or "closed tube" to observe—

a. **Changes of Colour,** as in arseniates and phosphates of copper, *chalybite,* etc. The operator should observe whether the original colour is restored on cooling.

b. **Decrepitation,** which generally takes place in anhydrous minerals having distinct cleavage, such as *blende* and *wolfram.* It appears to be due to the presence of a little moisture, between the laminæ of which the mineral is composed.

c. **Fusion,** which may be *partial,* as in many minerals of the *alum, salt,* and *vitriol* groups, which fuse at first in their water of crystallization but finally solidify, leaving an insoluble residue of various colours; or *complete,* as in the case of *sulphur, cryolite,* and a few other minerals which fuse at a low temperature.

d. **Moisture,** which settles in drops on the side of the tube, as in all hydrated minerals. The student should ascertain whether this moisture is acid, neutral, or alkaline, by means of a piece of test paper; and whether it is acid from the first, or only when the temperature is pretty high. Thus in *nitrates* the water will probably be acid from the first, but in *sulphates* it may only be acid when a high temperature is used.

e. **Sublimation.**—The sublimates may be—

1. *White,* melting to colourless drops on heating, indicating *tellurium;* to yellow drops, indicating *sulphur;* or to brown drops, indicating *selenium;* volatilising without melting, indicating *arsenic,* etc.
2. *Red, yellow,* or *brown,* usually indicating both sulphur and arsenic.
3. Black, metallic, indicating *arsenic.*
4. Grey, metallic, collecting into drops when rubbed, indicating *mercury.*

f. **Vapours or Odours** are best distinguished by the next operation.

(2). Heating in open tube, when *arseniates, sulphides, tellurides, selenides,* and *nitrates,* will give off characteristic odours, and deposit characteristic sublimates.

(3). Heating on charcoal, to observe—

a. **Deflagration**, indicating *nitrates.*

b. **Reduction** to a bead of metal showing the presence of Au, Ag, Cu, Pb, Sn, Bi, Sb, etc., or several of them together, which may be recognised by their colour, malleability, or brittleness, as well as by their solubility and other chemical tests.

c. **Fusibility.**—This should be compared with that of fragments of a similar size from the scale of fusibility.

d. **Vapours or Odours.**—Sulphureous, indicating *sulphur;* alliaceous, indicating *arsenic;* resembling horse-radish, indicating *selenium;* fetid or resembling rotten eggs, also indicating sulphur in a sulphide, etc.

e. **Incrustations.**—

1. *White,* near the assay, little or no odour, indicating *antimony.*
2. *White,* farther from the assay, garlic odour = *arsenic.*
3. *White,* yellow while hot, white malleable bead of metal in this or the fifth operation = *tin.*
4. *The same,* no malleable bead = *zinc.*
5. *Yellow* or *orange,* grey malleable bead = *lead.*
6. *Yellow, red,* or *brown,* grey brittle bead = *bismuth.*
7. *Dark red,* white malleable bead = *silver.*

f. **Complete Volatilization**, as in *native arsenic, sal-ammoniac.*

g. **Combustion**, rapid as in *sulphur,* slow as in *graphite.*

h. **Flame Colouration.**—The extreme tip of the flame is sometimes coloured—

1. *Blue = sulphur, arsenic, antimony, ores of copper, containing Cl or Br, selenium, lead,* etc.
2. *Green = barium, boracic acid, borates,* and *phosphates, some ores of copper, molybdenum, tellurium,* etc.
3. *Red = lithia, strontia, lime,* etc.
4. *Violet = potash.*
5. *Yellow = soda.*

These results are often better seen in the eighth operation—

i. **Non-volatile residue remains.**—These may be tested by the fourth and fifth operations.

(4). Treatment with cobalt solution.—This is only to be used in cases when the residue or coating from (3) is white or nearly white. A drop of nitrate of cobalt is dropped upon the residue or coating, and it is again heated. The following are assumed on cooling :—

a. *Blue,* alumina, silica.
b. *Red* or *flesh-colour,* magnesia, tantalic acid.
c. *Green,* zinc, tin, titanic acid, hyponiobic acid, antimonic acid.
d. *Brownish-red,* baryta.
e. *Violet,* zirconia, phosphate or arseniate of magnesia.

If a bright intense glow is observed on heating, *strontia, lime, magnesia,* or *zinc* are probably present.

(5). Treatment with carbonate of soda on charcoal.—This is adopted when the residue from (3) is not white. The reducing flame should be used, and the object is to obtain a bead of metal. The metals discovered may be—

a. Gold, yellow and malleable.
b. Silver, white and malleable, not easily oxidisable.
c. Tin, the same, but very easily oxidisable.
d. Copper, red and malleable.
e. Lead, grey and malleable.
f. Bismuth, grey and somewhat brittle.
g. Antimony, grey and very brittle.

When two or more metals are present the results are often intermediate. Should there be a strong effervescence while fusing with the carbonate of soda, a silicate is likely to be present.

(6). Borax bead.—This should only be applied to the non-volatile residue of (3). The presence of several metals or oxides together may modify the trials produced, but the following, with many others, are likely to be met with :—

a. Blue in both flames = *cobalt.*
b. Green in both flames = *chromium.*
c. Bluish-green in OF, red in RF = *copper.*
d. Violet or *amethystine* in OF, colourless in RF = *manganese.*
e. Reddish yellow OF, dirty green RF = *iron.*
f. Yellow OF, fine green RF = *vanadium.*

(7). Microcosmic bead.—The results in this operation are much the same as in (6), but some of the reactions are a little more easily distinguished, others somewhat less so in the presence of other oxides, and some of the colours are different. *Uranium, titanium,* and *tungsten,* give in OF a colourless or clear yellow bead; in RF *uranium* gives a fine green, *tungsten* a beautiful blue, which is green while hot, *titanium* a violet bead. Silica is insoluble in "micro" and remains visible in the bead.

(8). Heating in Pt forceps (or twisted in a coil of Pt wire).—This must only be adopted with minerals which the former operations have shown to contain neither easily reducible metals, nor arsenic or sulphur. The student must observe—

a. **Fusibility,** as compared with the "scale of fusibility."
b. **Changes of Colour,** as in *limonite, chalybite,* etc.
c. **Flame Colouration,** as in (3) *h.*

d. **Magnetism** (acquired) of the assay, as in *chalybite.*
e. **Swelling up** of the assay, as in *stilbite.*
f. **Glowing**, without fusion, as in *calcite.*
g. **Vermiculation**, as in *vermiculite.*
h. **Exfoliation**, as in *pyrophyllite.*
i. **Alkalinity** (acquired), as in the *alkaline earths.*

Besides, or instead of, the above eight "operations," there may often be an advantage in using the "pyrologic" methods, recommended by Major Ross in his recently published and valuable work on *Pyrology;*[*] such as the use of boric and phosphoric acid beads, of a plate of aluminium for sublimations, and many others.

205. Special Tests.—Among special and very delicate reactions for particular substances may be mentioned the following:—

a. **Bismuth.**—Small quantities of bismuth may be detected by mixing the powdered assay with iodide of potassium and sulphur, and heating on charcoal. A bright red coating indicates bismuth.

b. **Boron** may be detected in silicates or other minerals by making the assay into a paste with Turner's test[†] and a little water, and heating with the tip of the oxidising flame. A yellowish-green tinge indicates boron.

c. **Copper.**—Moisten the powdered substance with HCl, or mix it with a little moist chloride of silver, and heat with the tip of the oxidising flame. A bright blue colour indicates copper.

d. **Chlorine.**—This is the converse of *c.* The assay is heated with oxide of copper.

e. **Manganese.**—Fuse on platinum foil with carbonate of soda. A green colour indicates manganese.

f. **Mercury.**—Mix with litharge or powdered charcoal in a dry closed tube, and heat strongly. Mercury will be deposited on the sides of the tube as a grey metallic coating if present.

g. **Phosphoric Acid.**—Heat strongly in a matrass with a fragment of magnesium wire, or of sodium; when cold add one drop of water. The presence of phosphorus is indicated by the disagreeable smell of phosphoretted hydrogen.

h. **Sulphur.**—Fuse on charcoal with carbonate of soda in RF; when cold place the bead on a surface of polished silver (*e.g.*, a silver coin). The presence of sulphur is indicated by a darkening of the coin, and a smell of sulphuretted hydrogen.

i. **Fluorine.**—This may generally be detected by strongly heating the assay in an open tube, in which is placed, at the cool end, a slip

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[*] *Pyrology or Fire Chemistry*, by W. A. Ross.

[†] 4½ parts of bisulphate of potash, one part of powdered fluor spar, mix.

of moistened Brazil-wood paper. With some silicates, as *tourmaline*, it is necessary first to mix the assay with phosphate of soda. The presence of *fluorine* is indicated by the paper becoming yellow.

It will also be necessary in some cases to test minerals as to their relative solubilities and other chemical characters, as mentioned in Art. 193; but the minutiæ of all such manipulations must be studied in works specially devoted to chemical and blowpipe analysis.

206. The Spectroscope.—For detecting certain substances which are often present in very small quantities, as sodium, potassium, lithium, calcium, strontium, barium, thallium, cæsium, rubidium, and indium, the spectroscope, fig. 579, or some other form of the instrument, will be found very useful.

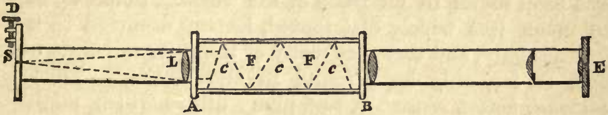

Fig. 579.

It is merely necessary in general to make a paste of the powdered mineral with HCl, to heat a little of this on a loop of platinum wire in the blowpipe flame, and to examine the flame with the spectroscope, when the characteristic bright lines will be seen, as described in most works on chemical analysis. Major Ross has devised a "spectrum lorgnette" to be used for this purpose, which is made by W. Browning of London.

CHAPTER XXVI.

DISTRIBUTION AND PARAGENESIS OF MINERALS.

207. Distribution.—Of the more common or more important minerals described in the second volume of this work, many have been found in all parts of the world. Some, however, are much less widely distributed, having occurred in a few localities only, and there are many of the rarer minerals which have, so far, only been found in one locality. Thus the *diamond*, *borax*, *cinnabar*, and many others which might be mentioned, are not known to have been found in the British Islands; and many other minerals, which are even very common in some countries, are here quite unknown as local products. On the other hand, several minerals have been found in these islands, and especially in Cornwall and Scotland, which have never yet been found elsewhere.

208. Paragenesis.—Some minerals occur chiefly or exclusively in granite, others in diorites or schists, others again in limestones, or in volcanic rocks. Moreover, certain minerals are commonly associated with other minerals, forming natural groups, which in some cases appear to have been formed contemporaneously. It is this latter kind of association, which is of so great assistance to the student in enabling him to recognise minerals at sight, much as specimens of the same mineral from different localities may differ in appearance. It is to this association also that the term *paragenesis* primarily applies, but its meaning has been extended so as to include all such associations of minerals in groups, or of minerals which are congenial to each other, as miners say. In the following lists a few of the better known examples of paragenesis only are set down. We have distinguished those minerals which have been found sometimes *enclosed* in the species referred to by printing them in italics.

Quartz is associated with orthoclase, *mica, tourmaline, chlorite,* chalybite, calcite, dolomite, baryites, fluor, *cassiterite, pyrites, chalcopyrite, limonite, hematite, göthite,* wolfram, cuprite, *copper, galena, blende,* bournonite, gold, etc.

Calcite, with *quartz, copper, chalcopyrite, pyrites,* etc.

Apatite, with hornblende, axinite, magnetite, garnet, topaz, schorl, cassiterite, wolfram, quartz, orthoclase.

Barytes, with galena, calcite, blende, chalcopyrite, pyrites, etc.

Argentite, with stephanite, arsenic, pyragyrite, etc.

Cassiterite, with quartz, schorl, chlorite, mispickel, pyrites, blende, wolfram, topaz, lepidolite, etc.

Chalcopyrite, with quartz, fluor, galena, blende, chalybite, dolomite, pyrites, calcite, etc.

Galena, with quartz, pyrites, chalcopyrite, blende, calcite, etc.

Pyrites, with quartz, cassiterite, chalcopyrite, galena, fluor, mispickel, limonite, cobaltite, smaltite, inverarite, etc.

Cuprite, with quartz, copper, malachite, chessylite, fluor, etc.

Fluor, with quartz, wolfram, chlorite, orthoclase, chalybite, calcite, etc.

Garnet, with *magnetite,* apatite, epidote, talc, mica, hornblende, limonite, etc.

Serpentine, with steatite, diallage, asbestos, copper, chrysocolla, calcite, chromite, and nickel ores.

Sulphur, with celestite.

Tellurium, with gold, bismuth.

Platinum, with iridium, rhodium, palladium, etc.

Gold, with quartz, tellurium minerals, etc.

Cinnabar, with tetrahedrite, quartz, calcite, etc.

Magnetite, with chlorite, garnet, hornblende, etc.

209. Succession of Minerals.—Von Weissenbach observed long since the following succession of bands or layers of minerals in the lodes of Freiberg, reckoning from the sides towards the centre of the veins :—

1. **Quartz,** containing pyrites, blende, galena, and mispickel containing a little silver.
2. **Diallogite,** with brown spar and rich argentiferous tetrahedrite, as well as the metallic minerals mentioned in 1.
3. **Chalybite,** with fluor and barytes and the ores mentioned in 2.
4. **Calcite,** with rich silver ores.

Similar successions of deposits have been observed in Cornwall, Wales, and other mining districts, all tending to show that, in a given locality, different solutions have successively occupied the fissures and deposited minerals upon their walls. Every cabinet of minerals affords evidence of the same nature.

210. Relative Age of Mineral Deposits.—There is still much obscurity existing on this subject, but the following generalizations are pretty generally accepted:—

a. Tin deposits are generally older than the carboniferous period. They appear mostly to have been formed at great depths.

b. Deposits of gold, silver, lead, zinc, copper, cobalt, nickel, and bismuth ores, occur of very dissimilar ages, but are generally more recent than the tin deposits, and they have been formed at moderate depths.

c. Iron and manganese ores have been mostly formed near the surface, but they are of all ages, like the rocks in which they occur.

It is still doubtful, however, whether these facts rest upon a real difference of age. If, for example, the tin deposits were formed at a great depth, they could only come to light after a long period of elevation and denudation, and similar deposits may even now be in process of formation at depths of several miles.*

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* There is good reason to believe that a certain amount of deposition of metallic ores is still going on in fissures and cavities of the rocks. In the abandoned workings of the Cornish mines stalactitic iron oxide is abundantly deposited, and metallic copper is often found precipitated upon decaying wood. Galena has also been found in crystals resting upon wood and iron, and a deer's horn, partly coated with crystals of oxide of tin, is preserved in the Museum of the Royal Geological Society at Penzance. Gold has also been found permeating masses of wood in the alluvial gold-fields of Victoria. In some instances it is probable that the mineral substance is only transferred over short distances, but in others it is probable that the mineral solutions are still supplied through fissures from great depths. On this subject Gustav Bischof's *Physical and Chemical Geology* may be studied with advantage.

CHAPTER XXVII.

ON ARTIFICIAL MINERALS AND "MINERAL GROWTHS."

211. Amorphous Substances.—Large numbers of minerals have the same composition as well-known artificially-prepared inorganic substances; and such substances might in one sense be all termed artificial minerals. Thus the hydrated oxides of iron, obtained by precipitation at different temperatures from ferruginous solutions, are the analogues of naturally occurring oxides, and so with many other chemical precipitates. Even the botryoidal, mammillary, and other imitative forms met with in nature, have their parallels in the substances prepared by the chemist, or in those resulting from the operations of miners and metallurgists.

212. Artificial Crystals.—We are in a great measure ignorant of the manner in which most of the crystals occurring in the mineral kingdom have been formed, as comparatively few have been reproduced by the chemist, and those which have been formed by artificial means are often smaller than the naturally-formed crystals. Crystals of quartz and carbonate of lime, for instance, occur of immense size in nature, but the crystals of these substances which have been formed artificially are almost microscopic in character.

Crystals may be formed in a variety of ways, as for instance—

a. Sublimation, or condensation from a state of vapour; ex. *sulphur.*
b. Solution, and subsequent evaporation, or cooling; ex. *nitre.*
c. Slow cooling from fusion; ex. *bismuth.*
d. Thermo-reduction; ex. *diopside, moss-copper.*
e. Action of vapours upon each other, or upon appropriate solids; ex. *cassiterite.*
f. Electrolysis, or galvanic decomposition; ex. *copper.*
g. Contact with decomposing organic matter; ex. *pyrites.*
h. "Spontaneous" change; ex. the so-called "*mineral growths.*"

As a rule, artificially formed crystals exhibit fewer modifications than those which are formed naturally.

213. Crystals formed by Sublimation.—We have already mentioned sulphur as an example of this mode of imitating the operations of nature. There is good reason to believe that sulphur, specular iron, and other minerals, have been so formed in nature around many volcanic vents, and the latter substance has been frequently observed as a furnace product in cavities of slag from blast furnaces.

Arsenolite occurs in the flues of arsenic refineries as *cubic* (octahedral) crystals at low temperatures, and as *rhombic* crystals at high temperatures.

214. Crystals resulting from Solution.—Nature is very easily imitated in this manner in the cases of substances soluble in water without decomposition. Large crystals of *alum, cyanosite,* and very many other salts soluble in water, are easily obtained. The modifications of the crystals, and sometimes, as in the case of carbonate of lime, even the system of crystallization depends upon the temperature of the solutions at the time of the formation of the crystals, as well as upon other causes. Bischof has shown that the great majority of the minerals found in fissures and rock cavities have been deposited from solutions. Becquerel has formed *apophyllite* by the action of potash on *selenite.*

215. Crystals due to Fusion, etc.—Occurring as crystallizations in or upon slags from metallurgical operations (furnace products). The following have been observed:—

Augite.
Chalcopyrite.
Diopside.
Fayalite.
Galena.
Gehlenite.
Graphite.
Labradorite.
Melilite.
Massicot.
Melaconite.
Molybdenite.
Mispickel.
Orthoclase.
Pyromorphite.
Rutile.

216. Thermo-reduction.—1. By heating appropriate substances without fusion, and leaving them to cool, as when "moss-copper" is formed on the surface of heated masses of copper regulus. 2. By mixing their constituents, or substances containing them, and heating at high temperatures. The following have been found by the experimenters whose names are attached:—

Anatase (*G. Rose*), by fusing titanic acid with microcosmic salt in the reducing flame, and then exposing for a short time to the oxidising flame.

Celestite (*Gages*), by fusing gypsum and chloride of sodium.

Chrysoberyl (*Ebelman*), by fusing alumina, glucina, and boric acid. (*Deville and Caron*), by fusing glucina and fluoride of aluminium in atomic proportions with boric acid.

Corundum (*Ebelman*), by heating strongly a mixture of borax and alumina. (*Gaudin*), by heating potash alum with charcoal. (*Deville and Caron*), by heating fluoride of aluminium and boric acid in a charcoal crucible with the addition of a little fluoride of chromium for the blue (sapphire); a little more chromium gives a red colour (ruby).

Diopside (*Berthier*).

Forsterite (*Ebelman*).

Franklinite (*Daubreé*) by fusing perchloride of iron, chloride of zinc and lime.

Garnet (*Daubreé, Studer*).

Idocrase (*Studer*).

Magnetite (*Deville and Caron*), by fusing peroxide of iron and boric acid.

Melaconite (*Becquerel*), by fusing lime with caustic potash.

Melanite (*Klaproth*), by fusing idocrase.

Mimetite (*Lechertier*), by fusing the arseniate and chloride of lead together.

Periclase (*Ebelman*), by fusing lime and borate of magnesia.

Perofskite (*Ebelman*), by fusing lime with silicate of titanium.

Rutile (*Deville*), by heating to redness titanic acid and peroxide of tin, and subsequent heating with silica.

Sphene (*Ebelman*).

Spinel (*Ebelman*), by fusing a mixture of alumina and magnesia with boric acid, adding chromic oxide for a red and peroxide of iron for a black colour. (*Deville and Caron*), by heating the fluorides of alumina and magnesia with boric acid.

217. By Passing Vapours over Heated Substances.—

Anatase, by passing steam over fluoride of titanium; also by passing steam over chloride of titanium (*Daubreé*); also by passing gaseous hydrochloric acid over titanic acid (*Deville*).

Andalusite, by passing fluoride of silicon vapour over alumina, also by passing fluoride of aluminium vapour over silica (*Deville and Caron*).

Blende, by passing the vapour of sulphur over the heated oxide or silicate of zinc (*Wurtz*).

Brookite, by passing steam over fluoride of titanium (*Daubreé*); also by passing steam over chloride of titanium (*Daubreé*).

Cassiterite—1. By passing gaseous hydrochloric acid over protoxide of tin (*Deville*). 2. By passing steam over heated perchloride of tin. (*Daubreé*). 3. By passing steam over heated fluoride of tin (*Daubreé*).

Corundum, by passing chloride of aluminium vapour over lime (*Daubreé*).

Diopside, by passing chloride of silicon vapour over magnesia (*Daubreé*).

Galena, by passing the vapour of sulphur over heated oxide of lead; also by passing the same vapour over silicate of lead (*Wurtz*).

Hausmannite, by passing gaseous hydrochloric acid over a mixture of sesquioxide of manganese and magnesia.

Hematite, by passing steam over heated perchloride of iron; also by passing gaseous perchloride of iron over heated lime.

Idocrase, by passing the vapour of chloride of silicon over the necessary bases (*Daubreé*).

Magnesioferrite, by passing gaseous hydrochloric acid over a mixture of peroxide of iron and magnesia (*Deville*).

Magnetite, by passing gaseous hydrochloric acid over heated peroxide of iron (*Deville*).

Periclase, by passing gaseous hydrochloric acid over heated magnesia (*Deville*), or over heated lime (*Daubreé*).

Rutile, the same as brookite, both methods (*Daubreé*).*

Spinel, by passing chloride of aluminium vapour over heated magnesia (*Daubreé*).

Wurtzite, by subliming blende in a current of sulphurous acid.

218. Galvanic Action.—The best known examples of the formation of new mineral substances by this agency are the so-called metallic trees. Gold, silver, lead, copper, bismuth, and many other metals are separated in the metallic state from their solutions by the action of metals, such as iron or zinc, which are more electro-negative than themselves. There is good reason to believe that many of the naturally-occurring capillary and arborescent forms of these metals met with in nature have been so formed, and the process is very easily imitated in the laboratory.

219. Contact with Decomposing Organic Matter.—There is good reason to believe that native gold, pyrites, and other minerals have often been separated from their solutions by the agency of decomposing organic matter.†

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* *Hautefeuille* says that in passing steam over fluoride or chloride of titanium, the result is the formation of *rutile* when the temperature employed is a red heat, *brookite* if the temperature is between those necessary for the volatilization of cadmium and zinc, and *anatase* when the temperature is a little below that of the volatilization of cadmium.

† See note to Chap. XXVI., page 190.

Galena has been formed by suspending sulphate of lead in a bag in water containing carbonic acid, and decomposing organic matter together with carbonate of lime (*e.g.*, a dead oyster in its shell); crystals of galena were deposited upon the shell (*Gages*).

Blende, pyrites, malachite, chalcocite, and selenite were formed in the same way, using appropriate salts (*Gages*).

Tallingite has been formed by the action of water upon ammonio-chloride of copper (*Kane and Graham*).

220. Spontaneous Change—"Growth" of minerals.—Many minerals exhibit proof of gradual increase of size in the "lines of growth" so often observable in crystals, the concentric structure of stalactites and botryoidal masses. Another kind of "growth" is seen in the efflorescence of sulphate of iron upon pyrites, arseniate of cobalt upon smaltite, etc. Attention has recently been drawn to still another kind of mineral "growth," by Professor Liversidge, Mr. T. A. Readwin, Mr. W. M. Hutchings, and others, in the *Mineralogical Magazine* and the *Chemical News*. Mr. Readwin states that he has, in a great number of instances, observed in minerals, which have never left his possession, the development of "growths" of metallic gold, silver, copper, etc., and he suggests that mineralogists should pay particular attention to the state of specimens in their cabinets at intervals, so as to detect such changes as may be going on in the specimens from time to time.*

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* For full particulars on this interesting subject the student is referred to the *Mineralogical Magazine*, No. 5, published by Messrs. Simpkin, Marshall, & Co., of London, and Messrs. Lake & Lake, of Truro. Of course it is not intended, by using the term "growth" in this connection, to convey the idea that there is anything analagous to the growth of animals or plants.

EXAMINATION QUESTIONS.

(*The figures in parenthesis refer to the Sections in which the Answers may be found.*)

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1. Define accurately the term *mineral*, and state what substances ordinarily classed as minerals are excluded by this definition (1).

2. In what does a *rock* differ from a *mineral?* (2).

3. Mention ten of the principal *rock-forming* minerals (2).

4. What do you understand by the terms *crystalloid* and *colloid?* Give examples (6).

5. Define the terms *crystallised*, *crystalline*, and *cryptocrystalline*, as applied to minerals (8).

6. What are the chief imitative forms of minerals? Give examples of each (9).

7. What are *stalactites* and *stalagmites*, and how are they formed? (10).

8. What do you understand by the terms *edges*, *angles*, and *faces*, as applied to crystals? (12).

9. What are the *axes* of crystals? (13).

10. What are the *elements* of crystals? (14).

11. What do you understand by crystallographic notation? Give an example showing the application of the different symbols adopted by Mitchell, Miller, and Naumann (15, 16).

12. What are the *normals* of a crystal? (18).

13. What do you understand by the terms *zone*, *zone-plane*, *zone-circle*, and *zone-axis* as applied to crystals? (19).

14. What is a sphere of projection? (17, 27).

15. What is a crystallographic *form?* What are *holohedral*, *hemihedral*, and *tetartohedral* forms? (20).

16. What is a *combination* in crystallography? (21).

17. Give a brief account of the different *systems* of crystallography (22).

18. Describe the different methods adopted for representing crystals (23).

19. What are the ordinary *positions* adopted in representing crystals by sketches? (24).

20. What is a crystal map? (25).

21. Describe the difference between the *orthographic* and the *stereographic* projections (25).

22. What are crystal nets? Draw nets for the regular octahedron and the cube (28).

23. Draw the seven holohedral forms of the cubical system, and mark the positions of the axes (30-36).

24. Give a tabular form of Miller's, Mitchell's, and Naumann's symbols for each of the holohedral forms of the cubical system (30-36).

25. What are the *limits* of the deltohedron, the rhombic dodecahedron, the three-faced octahedron, the four-faced cube, and the six-faced octahedron? (32-36, 45).

26. Draw a sphere of projection for the cubical system (37).

27. Sketch the hemihedral forms of the cubical system, indicating the positions of the axes, and giving Miller's, Mitchell's, and Naumann's symbols (39-45).

28. Draw six different combinations of holohedral forms in the cubical system (47-48).

29. Draw six different combinations of holohedral with hemihedral forms in the same system (50).

30. Draw six different combinations of hemihedral forms with each other (51).

31. What are the *Platonic bodies*, and what are their properties? Which of them have been observed to occur in minerals? (53).

32. Describe the axes of the tetragonal system (55).

33. What are the angular elements of the tetragonal system? (56).

34. Describe the chief holohedral forms of the tetragonal system (57, 58).

35. Define the terms *prism*, *pyramid*, and *open forms*, as used in crystallography (57-59).

36. Explain the order in which crystallographic symbols are placed in combinations (60).

37. What is a sphenoid? (61).

38. Draw six hemihedral forms of tetragonal or ditetragonal pyramids (62, 63).

39. Draw a sphere of projection for the tetragonal system (66).

40. Draw six holohedral tetragonal combinations, the principal axis being placed vertically (67-69).

41. Draw the same six combinations in vertical projection (70).

42. Draw six tetragonal combinations, showing hemihedral planes (71-73).

43. What are the axes and elements of the *rhombic* system? (74).

44. Show how the *right rhombic pyramids* and the *derived rhombic pyramids* are related to the rhombic pyramid $h\,k\,l$ (75-77).

45. Show by a diagram the mutual relations of the *rhombic prisms* with the *macroprisms* and *brachyprisms* (78).

46. What are the symbols of the *right rectangular pyramid* and the *right rectangular prism?* (79, 80).

47. Draw six rhombic combinations, each of not less than three forms, and showing the symbols appropriate to each plane, placing the principal axis vertical (81-85).

48. Draw the same figures in vertical projection (86).

49. Define the terms *macrodome*, *brachydome*, *macropinacoid*, *brachypinacoid*, and *basal pinacoid* (75).

50. What rhombic forms are indicated by the symbols κhkl, πhkl, $shkl$? (87-90).

51. Draw a sphere of projection for the rhombic system (92).

52. Describe the axes of the *oblique* system (93).

53. What are the elements of the oblique system? (94).

54. Describe the principal forms of the oblique system (95-103).

55. Draw a map of the sphere of projection for the oblique system (103).

56. Draw six oblique combinations, and supply appropriate signs to the respective faces (104).

57. Describe the axes of the *anorthic* system (105).

58. Describe the elements of the anorthic system (106).

59. Draw a map of the sphere of projection of the anorthic system (110).

60. Describe the axes and elements of the *hexagonal* system (111, 112).

61. What are the chief holohedral forms of the hexagonal system? (113).

62. What are the chief hemihedral forms of the hexagonal system? (119).

63. Show the mutual relations of the rhombohedrons with the scalenohedrons in the hexagonal system (121).
64. Show the derivation of the rhombohedron from the double six-faced pyramid (120).
65. Draw twelve hexagonal combinations, supplying symbols to the respective faces, keeping the principal axis vertical (125-128).
66. Draw the same twelve combinations in *vertical projection* (128).
67. What is a macle, twin-crystal, or hemitrope? (129).
68. Define the terms *twin-axis* and *twin-plane* as applied to macles (129).
69. Draw three macles commonly occurring in the cubical system (130).
70. Draw two macles occurring in the tetragonal system (131).
71. Draw two macles occurring in the rhombic system (132).
72. Draw two oblique macles (133).
73. Draw two anorthic macles (134).
74. Draw four hexagonal macles (135).
75. What are the most commonly observed *twin-planes?* (136).
76. What are the chief "irregularities" of crystals (137).
77. Draw imperfectly developed crystals of alum, spinel, and garnet (138).
78. In what minerals are curved "planes" often met with? (139).
79. What do you know of *striations* and *roughnesses* on certain planes of crystals? (140).
80. What are *complex* or *polsynthetic* crystals? (140).
81. Mention several of the most commonly occurring "deceptive forms" met with among minerals (141).
82. What is *dimorphism?* give examples. Give examples of *trimorphism* (143).
83. What is *isomorphism?* give examples (144).
84. What is polymerous isomorphism? (145).
85. Give examples of crystalline aggregates (146).
86. State what you know of *pseudomorphism* (147-150).
87. What is the difference between *hypostatic* and *metasomatic* pseudmorphs? (148-149).
88. What are *anogene* and *katogene* pseudomorphs? (149).
89. State what you know of petrifactions (150).
90. What is a goniometer, and what is its use? (152-154).
91. Describe Carangeot's goniometer (152).
92. What is the principle of Wollaston's goniometer? (153).
93. How would you proceed to *read* a crystal? (155).
94. What are the chief physical properties of minerals? (157).
95. What are the principal directions of *cleavage* in the six systems of crystallography? (157).
96. Mention six minerals occurring in the cubical system having perfect cleavages parallel to the faces $1\infty\infty$ (157).
97. Mention six minerals in the tetragonal system having perfect cleavages, with the direction of those cleavages (157).
98. Do the same for the rhombic system (157).
99. Do the same for the oblique system (157).
100. Do the same for the anorthic system (157).
101. Do the same for the hexagonal system (157).
102. How would you distinguish by cleavage alone between rock-salt, zinc-blende, and fluor-spar? (157).
103. What are false cleavages? (158).
104. What are the chief varieties of *structure* observable in minerals? Give examples (159).
105. What are the chief varieties of *fracture?* Give examples (160).

106. State what you know of the relative *tenacity* or *frangibility* of minerals (161).

107. How far may the sense of touch be applied in discriminating minerals? (162).

108. What is the "scale of hardness," and how may it be applied in determining the hardness of a mineral? (163).

109. How would you distinguish rough fragments of rock-crystal, diamond, and topaz, without the aid of chemicals? (163).

110. If you had no "scale of hardness" by you, how would you determine approximately the "hardness" of a mineral? (166).

111. What precautions are necessary to be observed in experimentally determining the hardness of a mineral? (164).

112. How would you determine the specific gravity (*a*) of a mineral lighter than water; (*b*) of a mineral heavier than water; (*c*) of small fragments of a mineral? (168).

113. Describe Nicholson's aræometer, and the method of using it (168).

114. How would you determine the proportion of gold in a nugget composed of quartz and gold weighing 2 oz., the specific gravity of which is 3·4, *without destroying the nugget?* (168).

115. How would you determine the specific gravity of a specimen of rock-salt? (168).

116. What minerals have the power of affecting the magnetic needle? (169).

117. What is the difference between *magnetic* and *diamagnetic* substances (169).

118. Define the terms *pyro-electric* and *frictio-electric*. Give examples of minerals to which these terms may properly be applied (170).

119. What are *analagous* and *antilogous* poles? (170).

120. State what you know of phosphorescence as regards minerals (171).

121. Define the terms *pyro-phosphoric*, *frictio-phosphoric*, *electro-phosphoric*, and *helio-phosphoric*, and give examples (171).

122. What are the chief optical properties of minerals? (173).

123. How far is colour a useful aid to the recognition of minerals? State what you know of Werner's colours (174).

124. Define the terms *pleochroism*, *dichoroism*, and *trichroism* (175).

125. What is *chatoyancy*, and in what mineral has it been observed? (176).

126. What is *iridescence?* When it occurs in minerals, to what physical phenomenon is it due? (177).

127. What is *opalescence*, and in what mineral does it occur? (178).

128. State what you know of *fluorescence* (179).

129. How far is the streak of a mineral a useful guide in discrimination? State the colour of the streak in three minerals (180).

130. What is the difference between the *streak* and the *scratch* of a mineral? (180).

131. What are the varieties and degrees of *lustre* observable in minerals? Give examples (181).

132. What are the degrees of transparency or *diaphaneity* observable in minerals? (182).

133. Draw characteristic crystals of garnet, galena, leucite, fluor, diamond, tetrahedrite, blende, boracite, pyrites, and cobaltite (chaps. v. to vii.)

134. What is "refraction?" State the "law of refraction," and illustrate it by a sketch (183, 184).

135. What is "double refraction?" What is the distinction between the *ordinary* and the *extraordinary* ray? (185).

136. In what minerals may the phenomena of double refraction be best observed? (185).

137. State what you know of *polarised* light. How may light be polarised? (186).

138. Describe the *tourmaline pincette*, and the mode of using it (186).

139. What is a Nicol's prism, and how is it constructed? (187).

140. Make a sketch of a table polariscope, and say what phenomena may be observed by it (188).

141. How far are the optical properties of crystals dependent upon their crystalline form? (185, 189).

142. What is a dichroiscope, and for what is it used? (190).

143. How far may the sense of taste be applied in the discrimination of minerals? (191).

144. What minerals have distinct *odours?* (192).

145. In testing the *solubility* of minerals, how would you proceed, and for what kind of phenomena would you be on the watch? (193).

146. What is the "scale of fusibility?" (195).

147. Mention six minerals which are insoluble in water, HCl, HNO_3, H_2SO_4, and aqua regia (194).

148. What are chemical *elements?* Mention twelve of the most common, distinguishing gases, metals, and solid metalloids (198).

149. What is a chemical formula? (200).

150. How would you produce a *reducing* flame and an *oxidising* flame by means of the blowpipe? (203).

151. To what series of blowpipe operations would you subject an unknown mineral in order to determine its composition? (204).

152. Mention three substances which afford sublimates in the matrass.

153. Mention two minerals which decrepitate on heating (204).

154. Mention six substances which afford incrustations when heated on charcoal, with the colours of the incrustations (204).

155. Mention six substances which tinge the blowpipe flame, with the colours imparted (204).

156. How would you apply a solution of nitrate of cobalt in testing mineral substances? (204).

157. What are the characters of the beads afforded by ores of gold, silver, tin, copper, lead, and bismuth, when treated with carbonate of soda on charcoal? (204).

158. What colours are imparted to beads of *borax* or *microcosmic salt* in OF and RF by copper, chromium, cobalt, manganese, iron, vanadium, uranium, tungsten, and titanium? (204).

159. In heating minerals before the blowpipe in Pt forceps, what phenomena are to be looked for, and what precautions observed? (204).

160. Mention special and delicate tests for bismuth, boron, copper, chlorine, fluorine, manganese, mercury, phosphoric acid, and sulphur (205).

161. What substances may be best detected by means of the spectroscope, and what is the method of testing? (206).

162. Mention six minerals which are commonly associated with—

a. Quartz.
b. Apatite.
c. Cassiterite.
d. Chalcopyrite.
e. Pyrites.
f. Fluor.
g. Garnet.
h. Serpentine (208).

163. State the different ways in which crystals may be formed artificially, and give examples illustrative of each mode (212).

164. Mention twelve minerals which have been formed artificially (Chap. xxvii.).

165. State what you know of mineral "growths" (220).

INDEX

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